Increasing resolution in global models: biases and climate change

Eduardo Moreno-Chamarro

Louis-Philippe Caron, Pablo Ortega, Saskia Loosveldt Tomas, Javier Vegas-Regidor, Oliver Gutjahr, Marie-Pierre Moine, Dian Putrasahan, Christopher D. Roberts, Malcolm J. Roberts, Retish Senan, Laurent Terray, Etienne Tourigny, Pier Luigi Vidale

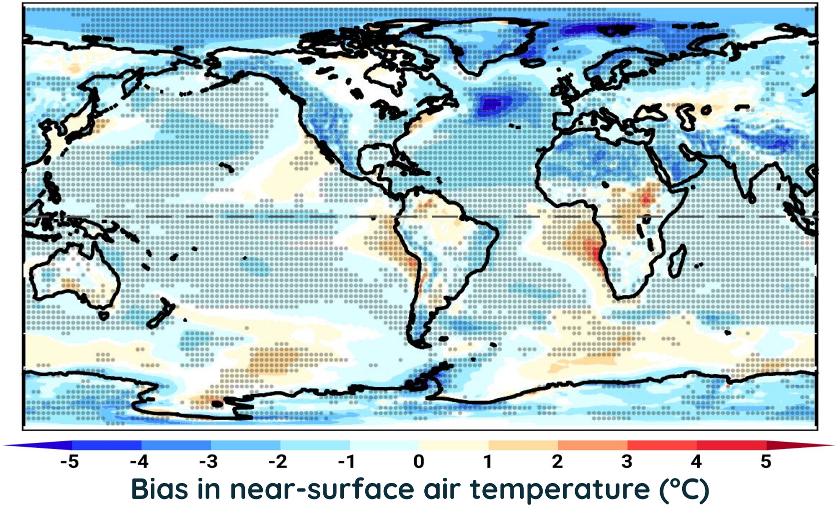
Ouranos
November 10, 2021

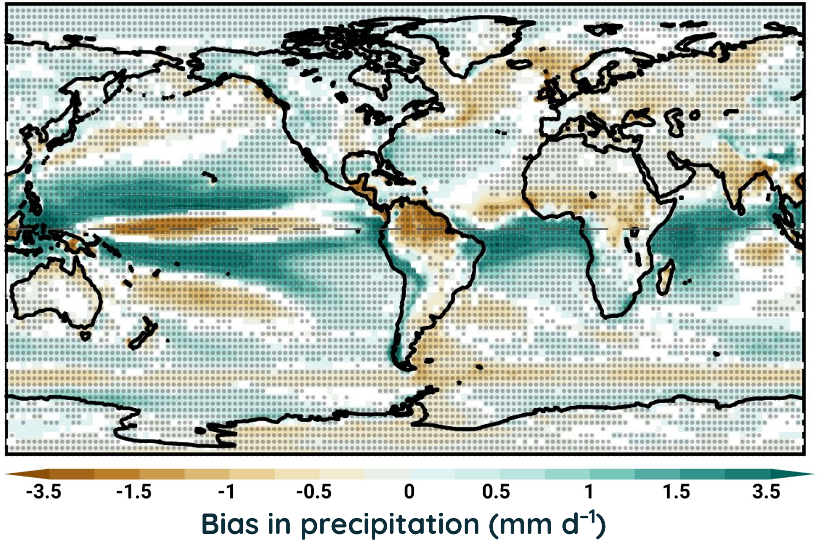
Biases in state-of-the-art climate models

Examples of well-known biases compared to observations persisting across model generations:

1. Warm southeastern tropical upwelling areas
2. Double ITCZ
3. Warm Southern Ocean
4. Cold North Atlantic

(Moreno-Chamarro et al., in review; GMD)





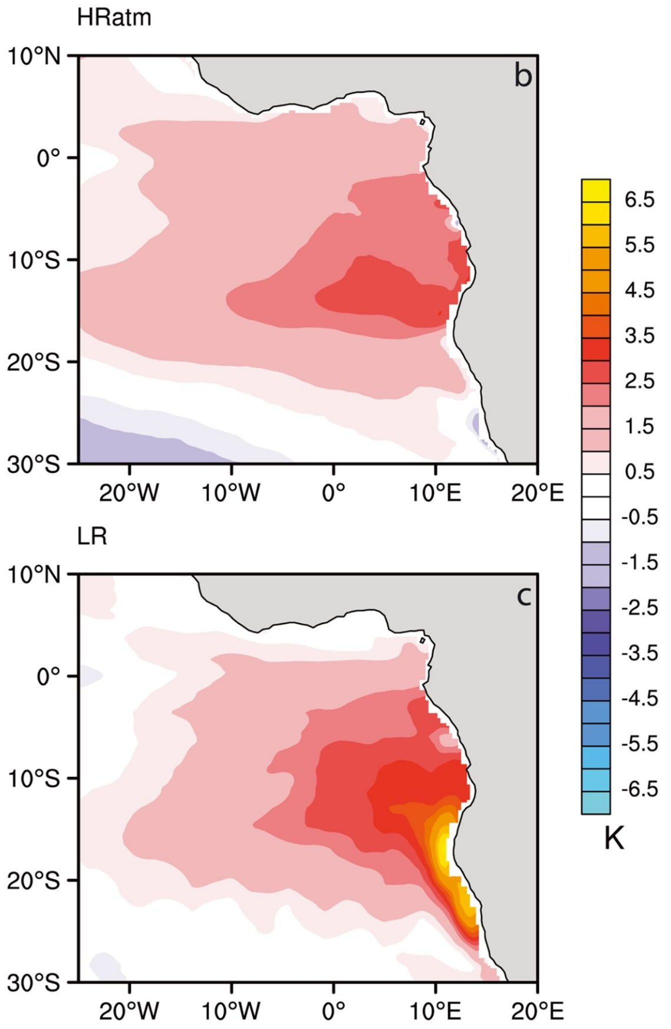
eduardo.moreno@bsc.es

Increased model resolution can help reduce model biases, but always and everywhere?

Example of bias reduction in sea-surface temperature off the western equatorial African coast with increased atmospheric resolution

Although reduced, the bias persists at high resolution

(Milinski et al., 2016; GRL)



To what extent does increased resolution (alone) help reduce biases?

Global models developed within the PRIMAVERA project

- Fully coupled
- Atmosphere-only, forced by historical sea-surface temperature

Historical simulations following the CMIP6 HighResMIP protocol

No additional tuning between resolutions: same model physics

- 4 NEMO ocean models *
- 2 IFS atmosphere models *

	CNRM-CM6-1 *		**EC-Earth3P** **		**ECMWF-IFS** **		**HadGEM3-GC31** *			**MPI-ESM-2**	
Resolution name	LR	HR	LR	HR	LR	HR	LL	HM	HH	HR	XR
Atmosphere nominal resolution (km)	207	75	107	54	80	40	217	41	41	134	67
Ocean resolution (degrees; km)	1° (100)	0.25° (25)	1° (100)	0.25° (25)	1° (100)	0.25° (25)	1° (100)	0.25° (25)	0.08° (8)	0.4° (50)	0.4° (50)

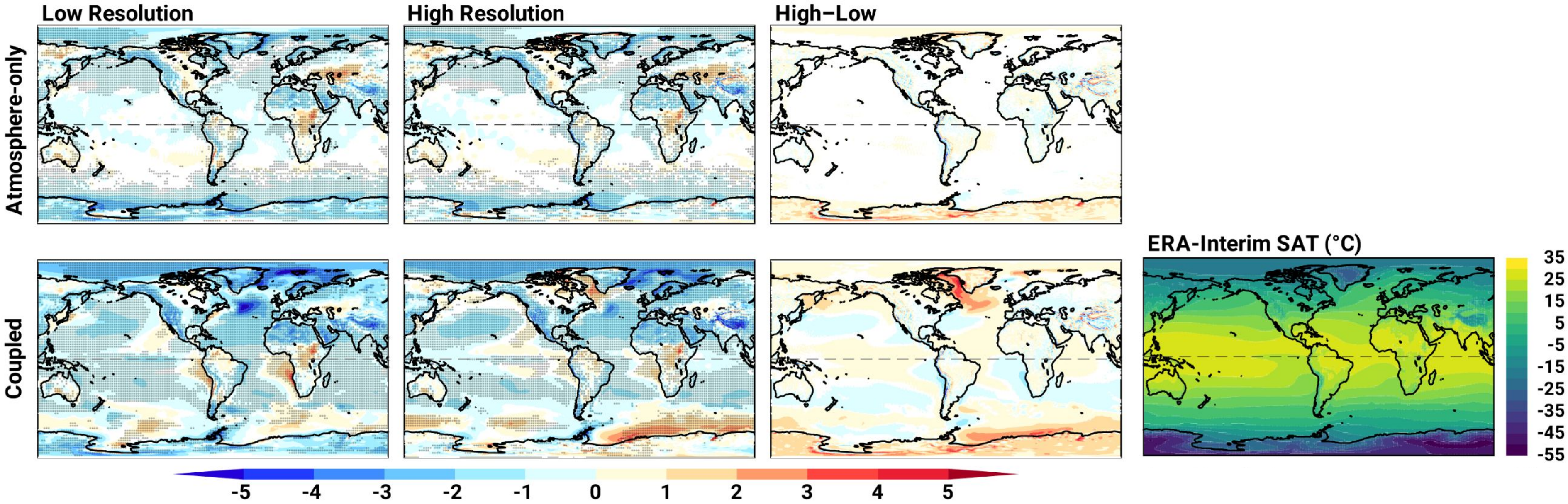
(Moreno-Chamarro et al., in review; GMD)

Reduction in temperature biases at higher resolution

Ensemble mean bias in near-surface air temperature (SAT; °C)

Well-known biases also in the ensemble mean of coupled models at low resolution

Slight bias reduction in upwelling regions and warming of the subpolar North Atlantic at high resolution



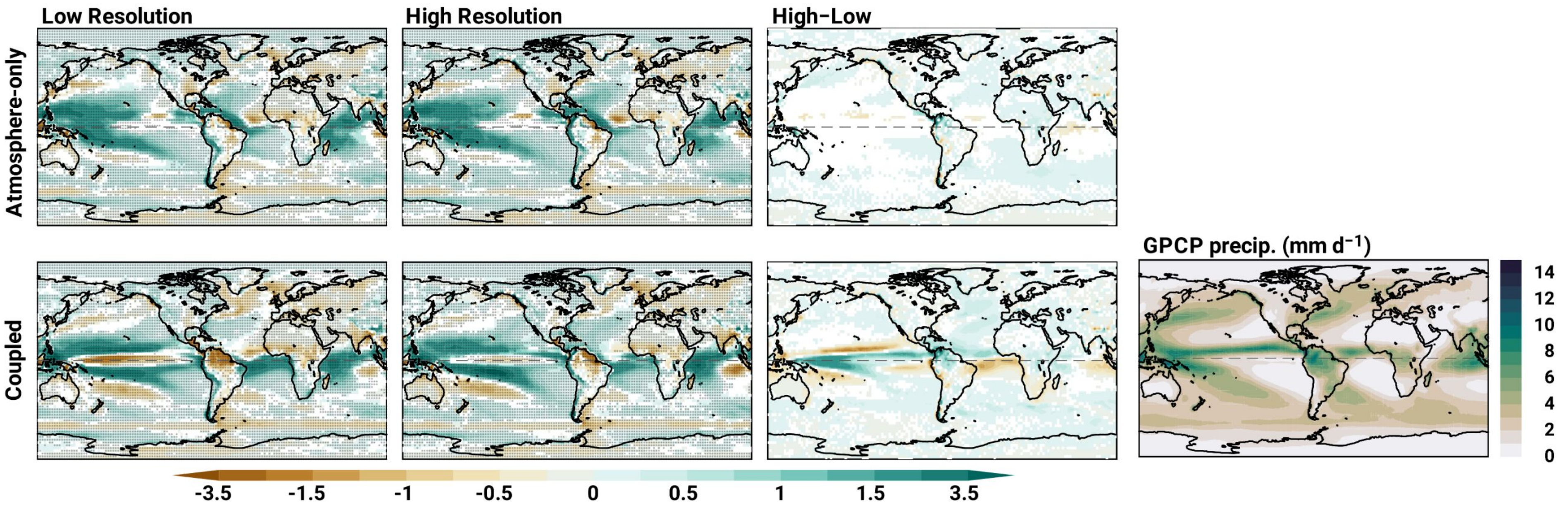
(Moreno-Chamarro et al., in review; GMD)

Persistent large biases in precipitation at high resolution

Ensemble mean bias in precipitation (mm d^{-1})

Insignificant bias reduction in the atmosphere-only models with increased resolution

Double ITCZ reduced in high-resolution coupled models

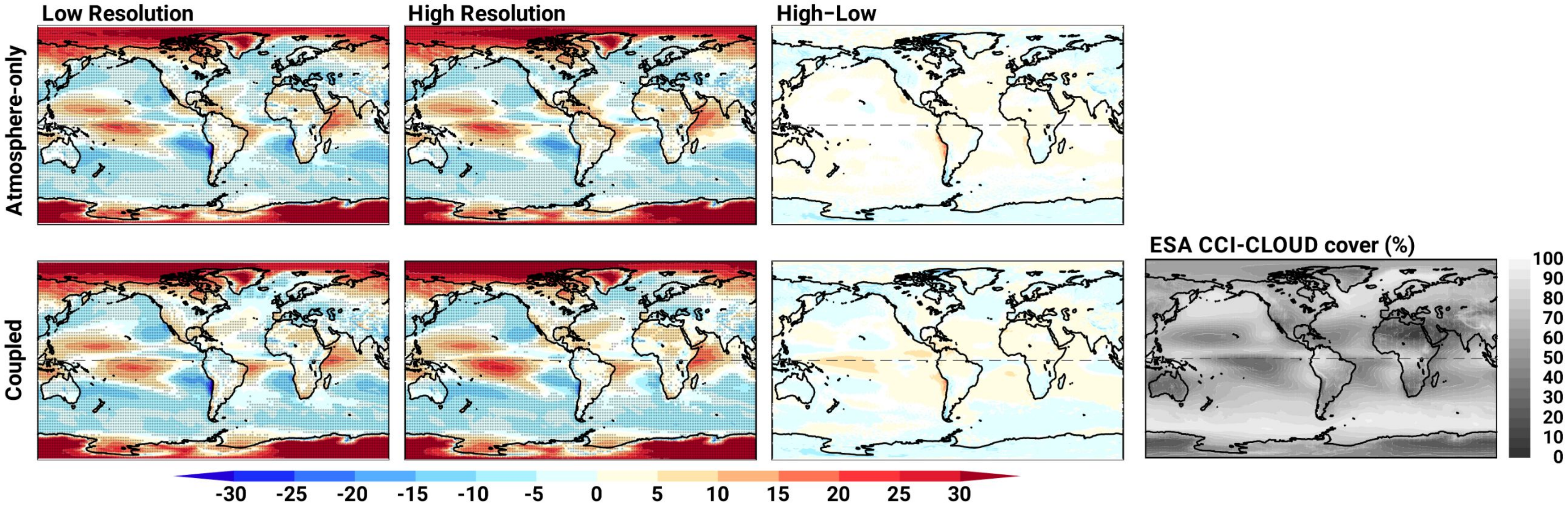


(Moreno-Chamarro et al., in review; GMD)

Biases in cloud cover insensitive to resolution or coupling

Ensemble mean bias in cloud cover (%)

Slight bias reduction in the upwelling regions but bias increase in the equatorial Pacific



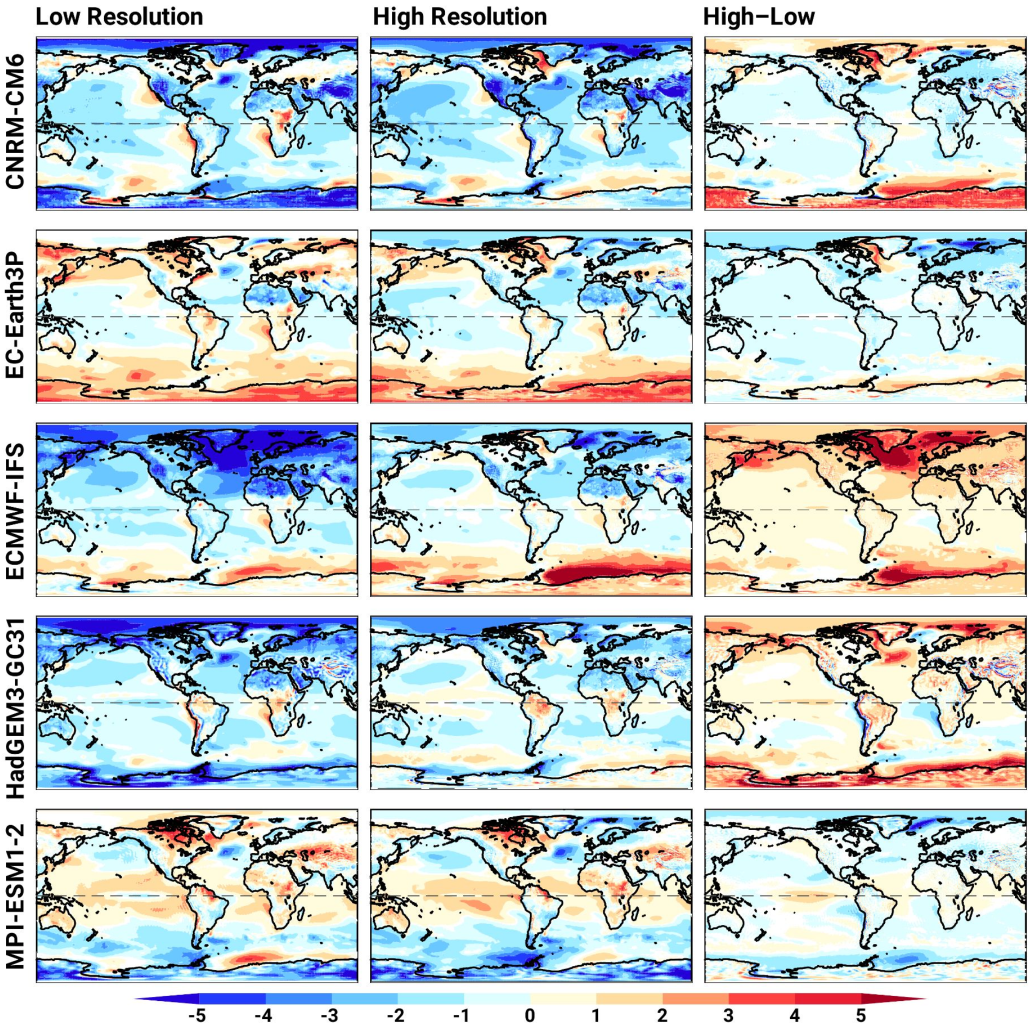
(Moreno-Chamarro et al., in review; GMD)

Large disparity across individual models

It complicates the analysis of a reduction in a particular bias

Increased atmosphere vs. ocean resolution vs. improved coupling?

E.g.: biases in temperature (°C) in each coupled models



eduardo.moreno@bsc.es

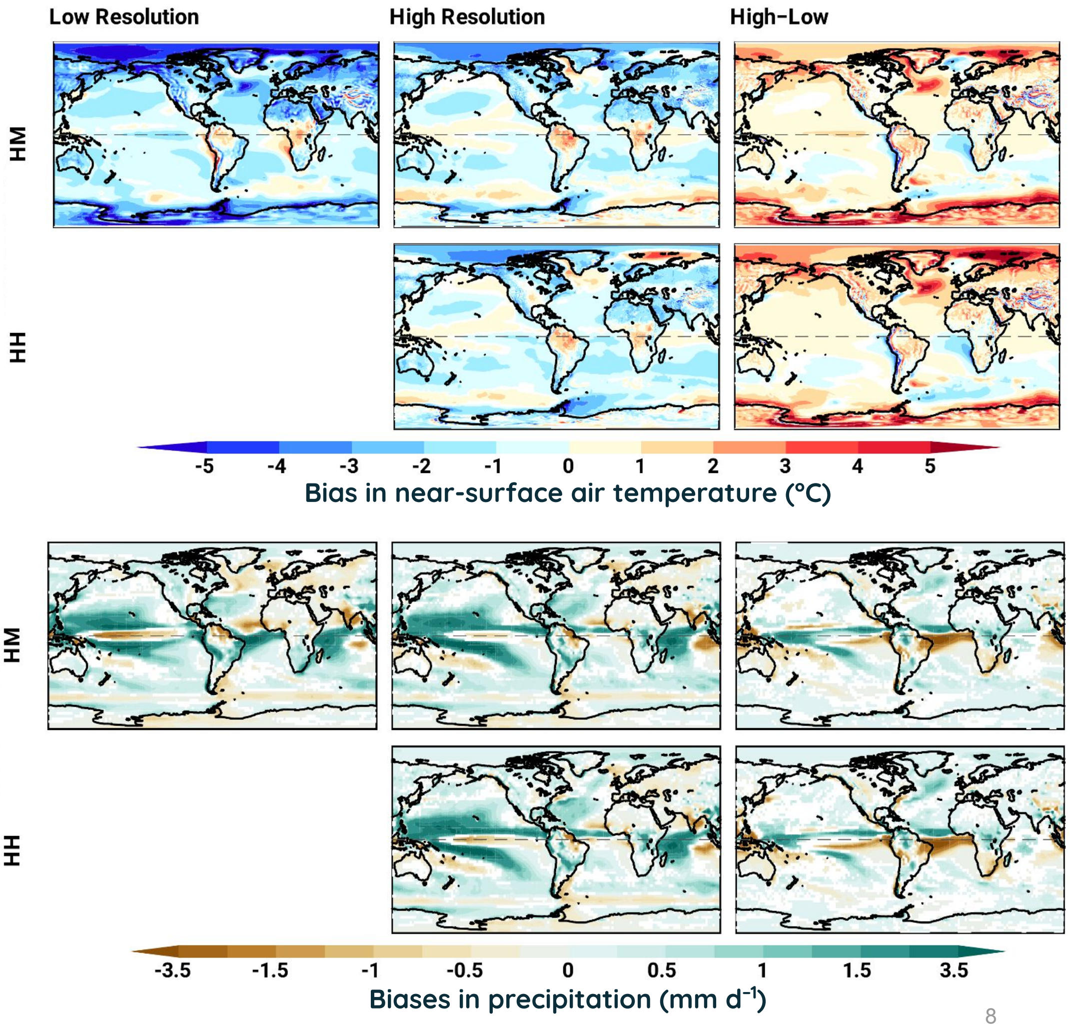
HadGEM3-GC31: one of the best improving models with increased resolution

Reduced biases

1. Tropical upwelling regions
2. Double ITCZ
3. North Atlantic

Similar bias reduction in eddy-present (~25 km; HM) and eddy-rich (~8 km; HH) ocean models coupled to a 50-km atmosphere model:

What is the benefit of reaching eddy-rich ocean resolution?



Extratropical cyclone activity increases when resolving the surface ocean mesoscale in temperature

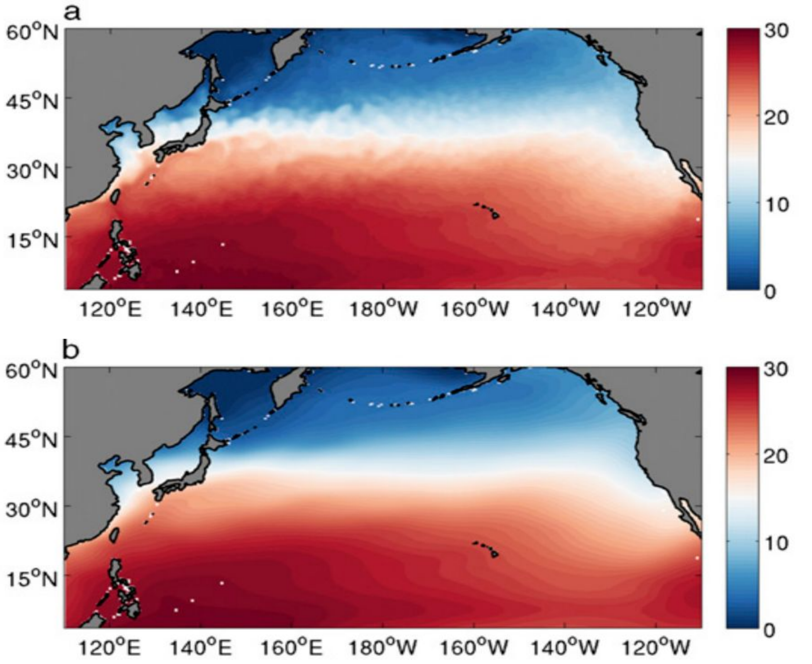


FIG. 1. Winter season (NDJFM) mean SST (°C) in (a) HR-CTRL and (b) HR-MEFS

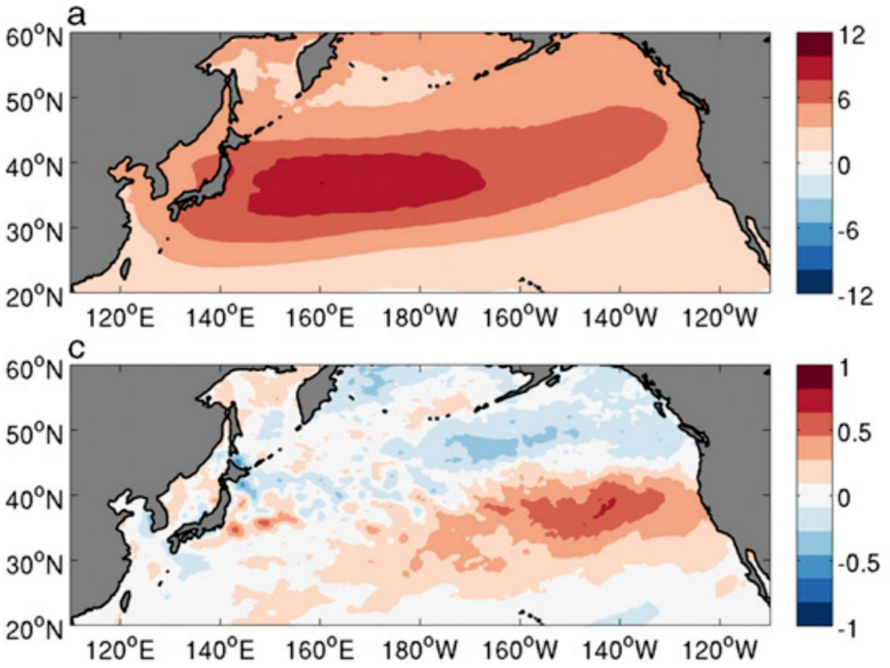


FIG. 7. Winter season mean Eady growth rate (10^{-1} day^{-1}) at 850 hPa computed from (a) HR-CTRL and (b) LR-CTRL. Difference of this growth rate (c) between HR-MEFS and HR-CTRL and (d) between LR-MEFS and LR-CTRL.

(Adapted from Ma et al., 2016)

Stronger future increase in extratropical cyclone activity at higher atmosphere resolution

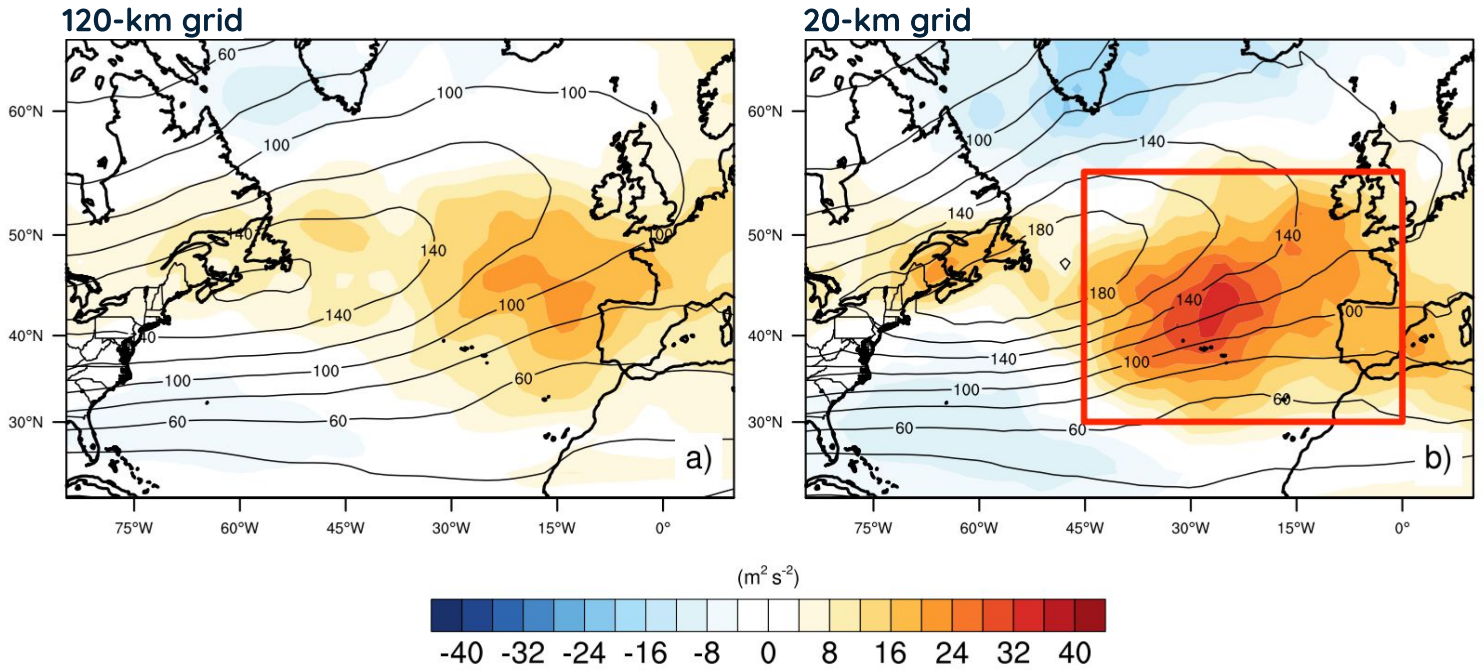


FIG. 2. Change in EKE with warming at 300 hPa (shaded) for (a) 120-km grid spacing and (b) 20-km grid spacing. Current-day values shown in contours (interval 20 $m^2 s^{-2}$).

(Willison et al., 2015)

Stronger future increase in extratropical cyclone activity at higher atmosphere resolution

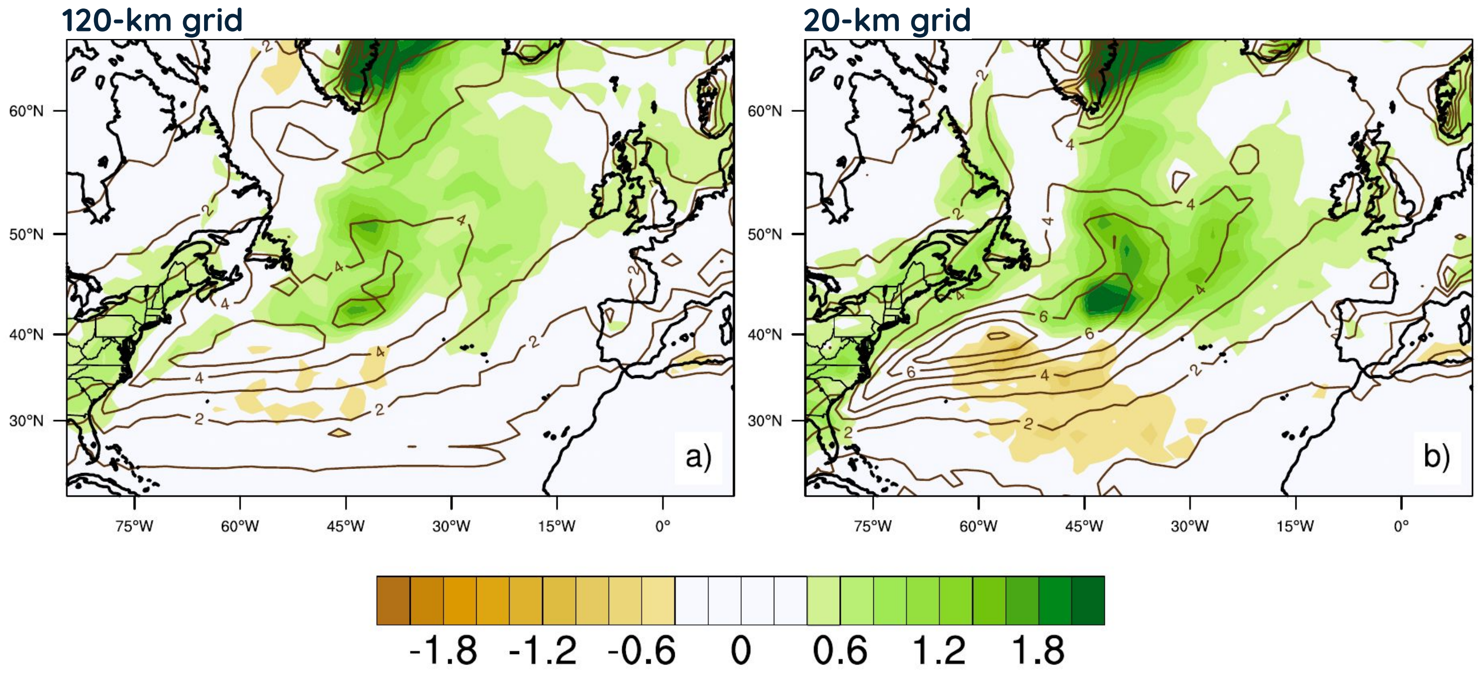
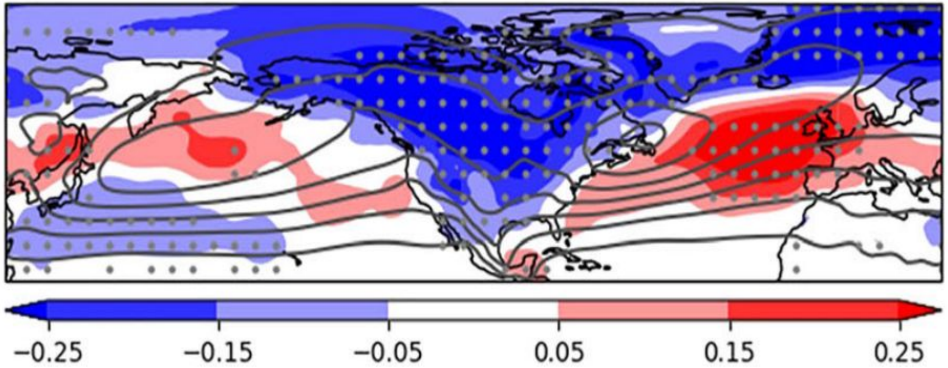


FIG. 6. Change in average JFM precipitation rate with warming (shaded; mm day^{-1}) at (a) 120-km grid spacing and (b) 20-km grid spacing. Current-day values are shown in brown contours (contour interval 1 mm day^{-1}).

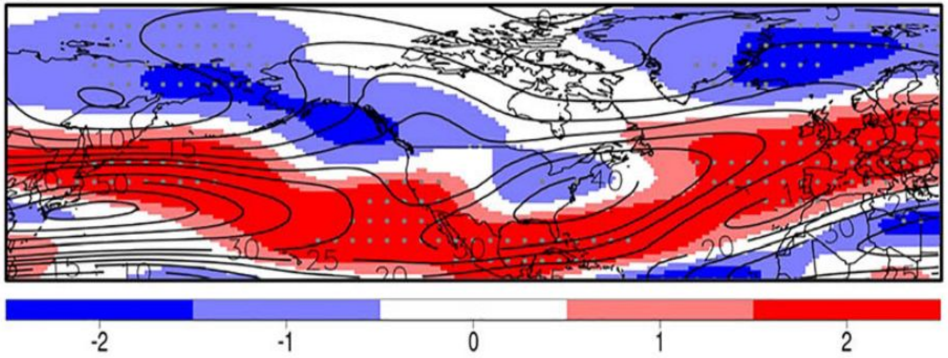
(Willison et al., 2015)

Increase in extratropical cyclone activity projected in CMIP6

CMIP6 DJF Storm Track (hPa)



CMIP6 DJF U250 (m/s)



Shading: Late-21st-century–Present-day difference in CMIP6 SSP2-4.4

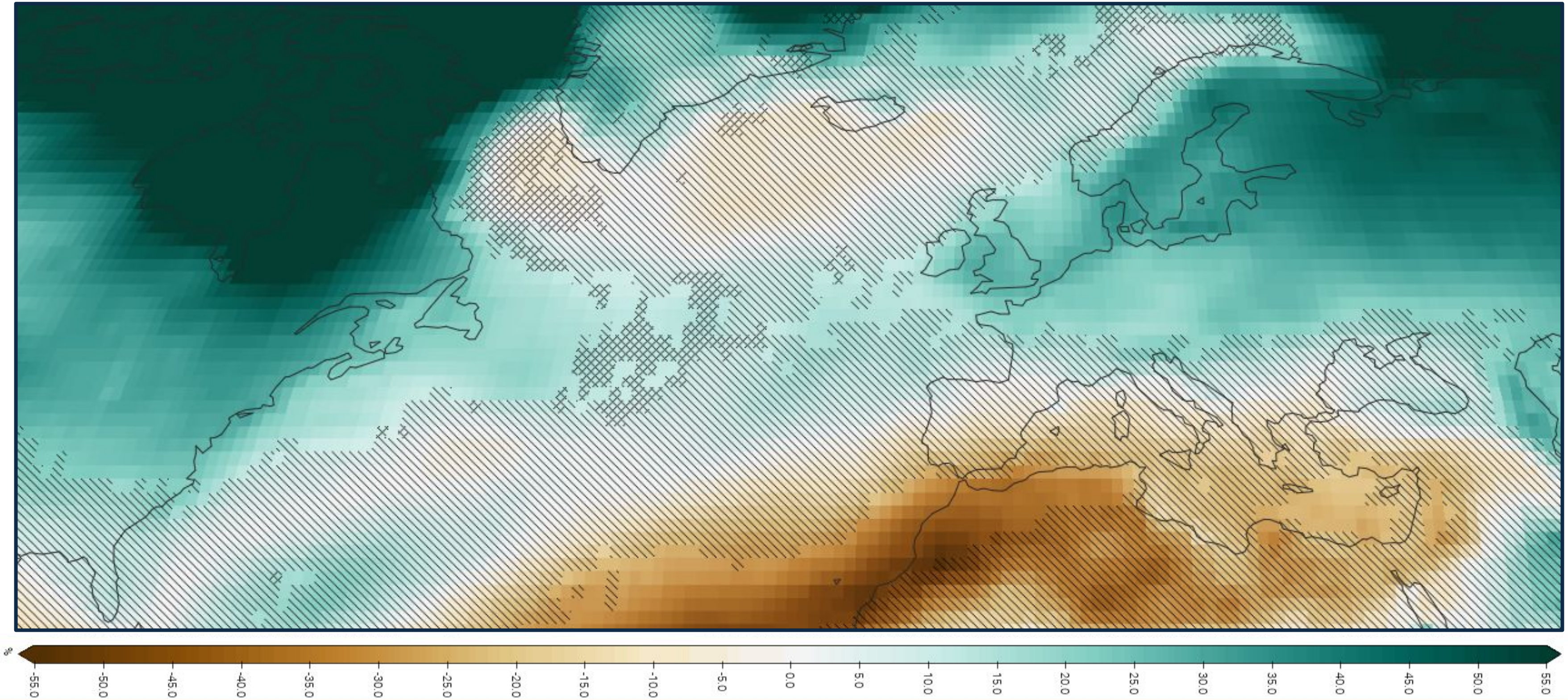
Contours: ensemble mean climatology

Dots: change significant at the 5% level

(Harvey et al., 2020)

Can we trust CMIP future projections of winter precipitation?

CMIP6 - Total precipitation change % - Long Term (2081-2100) SSP5-8.5 (rel. to 1961-1990) - December to February (33 models)



Can we trust CMIP future projections of winter precipitation?

CLIMATE NOW

How can big cities adapt to risks of floods?

By Copernicus • last updated: 06/04/2020

TEXT SIZE Aa Aa

Shifting climate patterns are leading to more unpredictable weather extremes and changes in urban infrastructures are leaving cities around the world exposed to floods.

Last November, mudslides swept through Europe's 2019 Capital of Culture, the Italian city of Matera as heavy rains battered the region of Basilicata. Authorities estimated damages to homes, businesses and infrastructure topped 8 million euros in damages. Typhoon Hagibis, the strongest to hit Japan since the late 1950s, cut electricity networks and flooded infrastructure across the country's cities. And areas less used to floods are starting to see more of these extreme events.

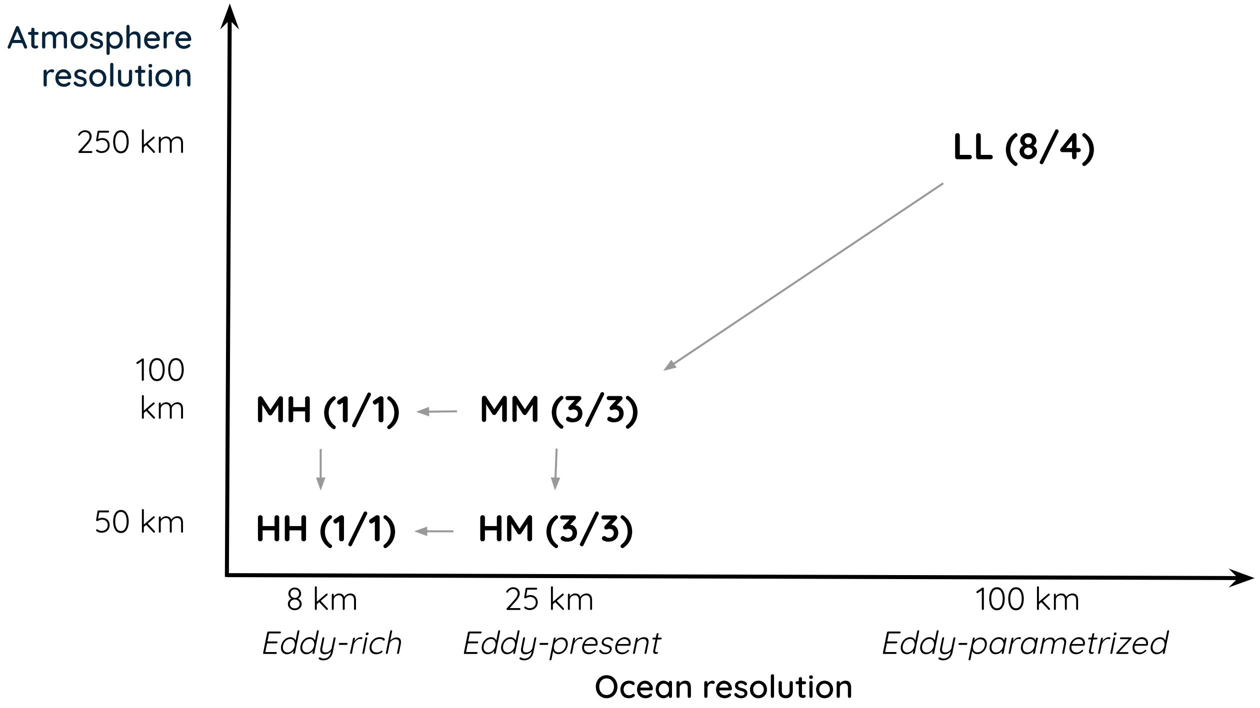
MOST VIEWED

1 Seaweed farming: an economic and sustainable opportunity for Europe

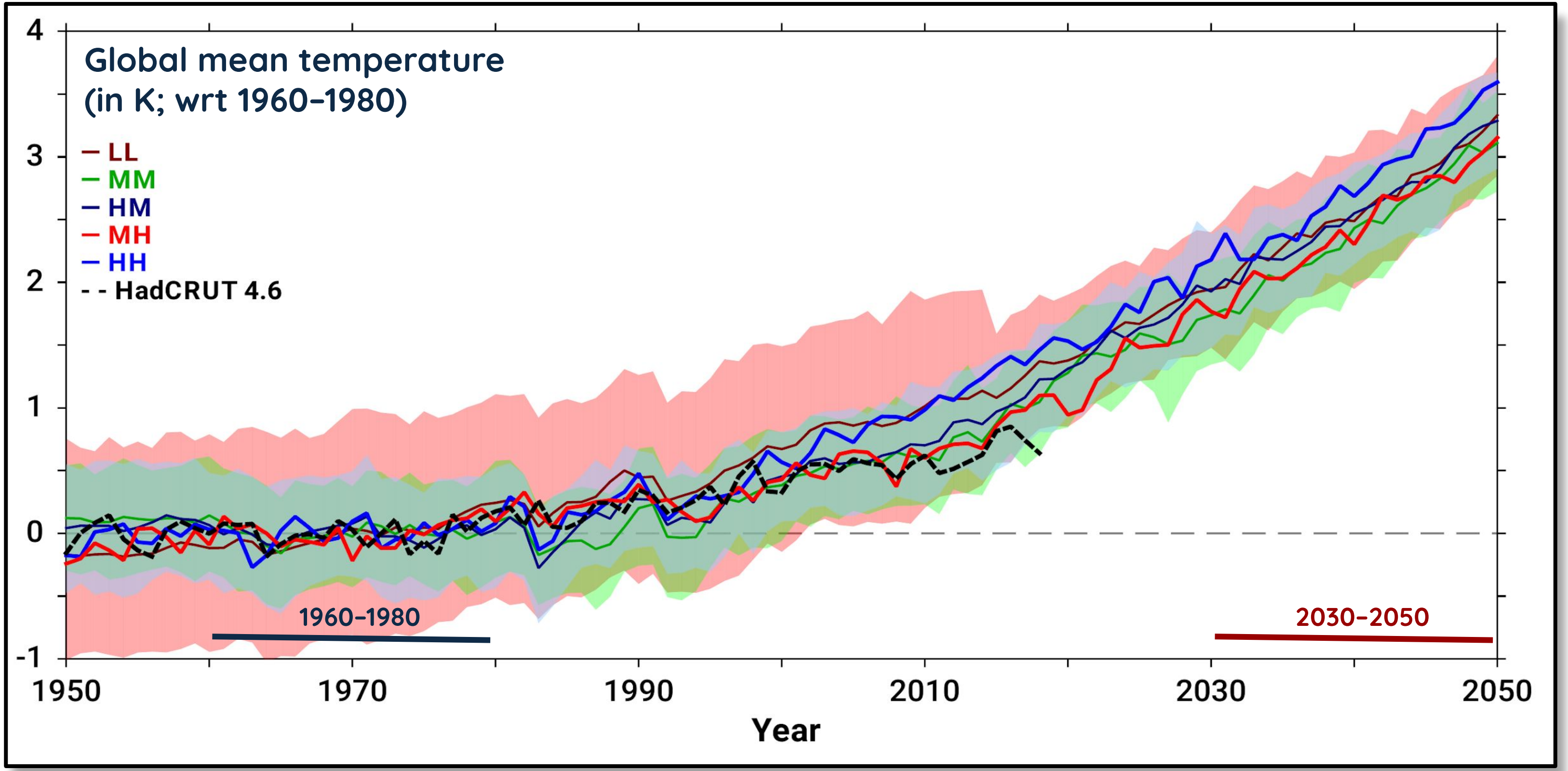
2 How EU funding is changing the face of Latvian innovation

Sensitivity to model resolution of future increases in winter precipitation over NW. Europe

CMIP6 HighResMIP **historical** and **SCP5-8.5** scenario simulations (1950-2050 period)
Five configurations of the Met Office's **HadGEM3-GC3.1** global model

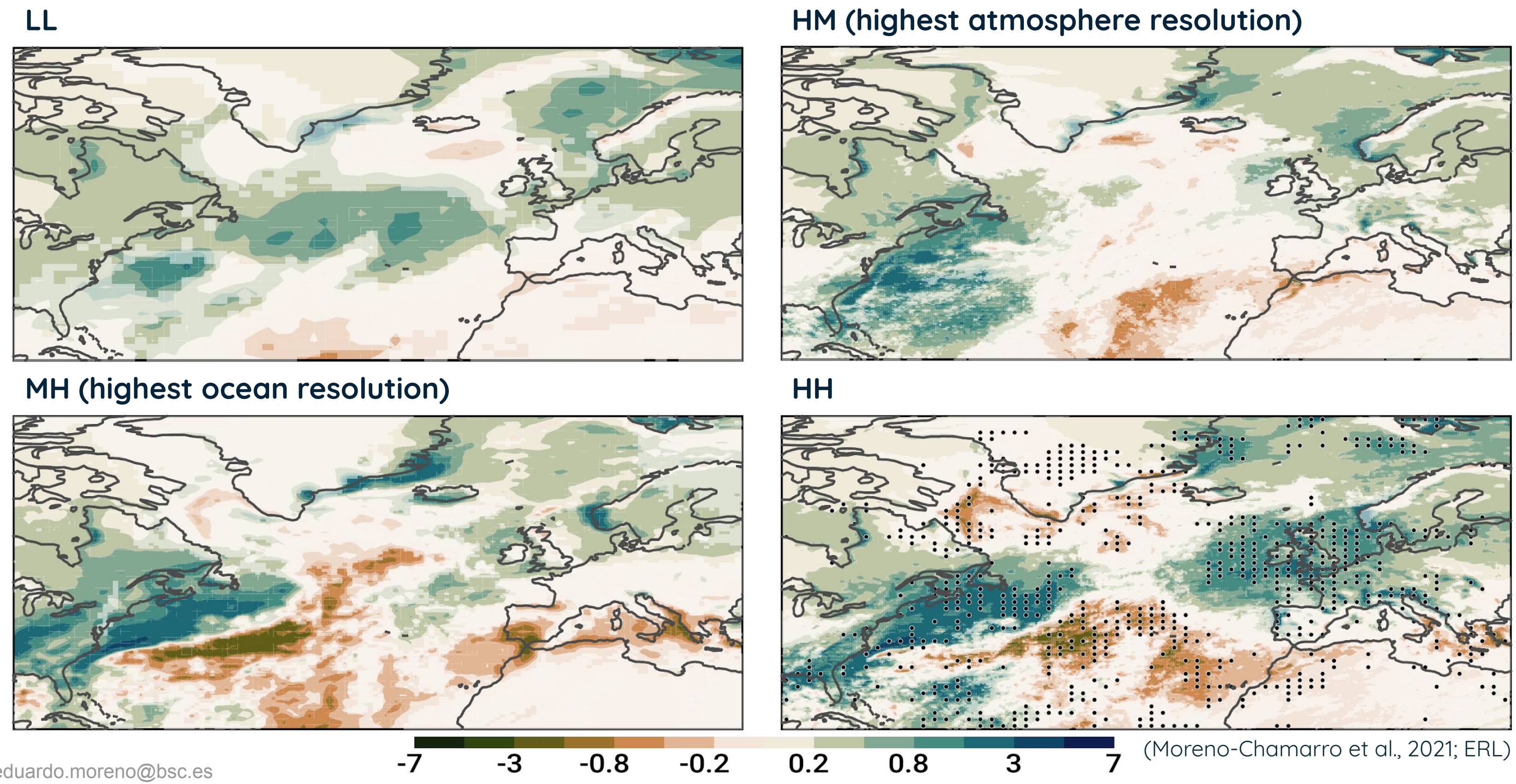


Similar global warming by 2050 for all the configurations



Winter precipitation increases the most in HH

Anomalies in winter precip. (mm/day) between 2030–2050 and 1960–1980

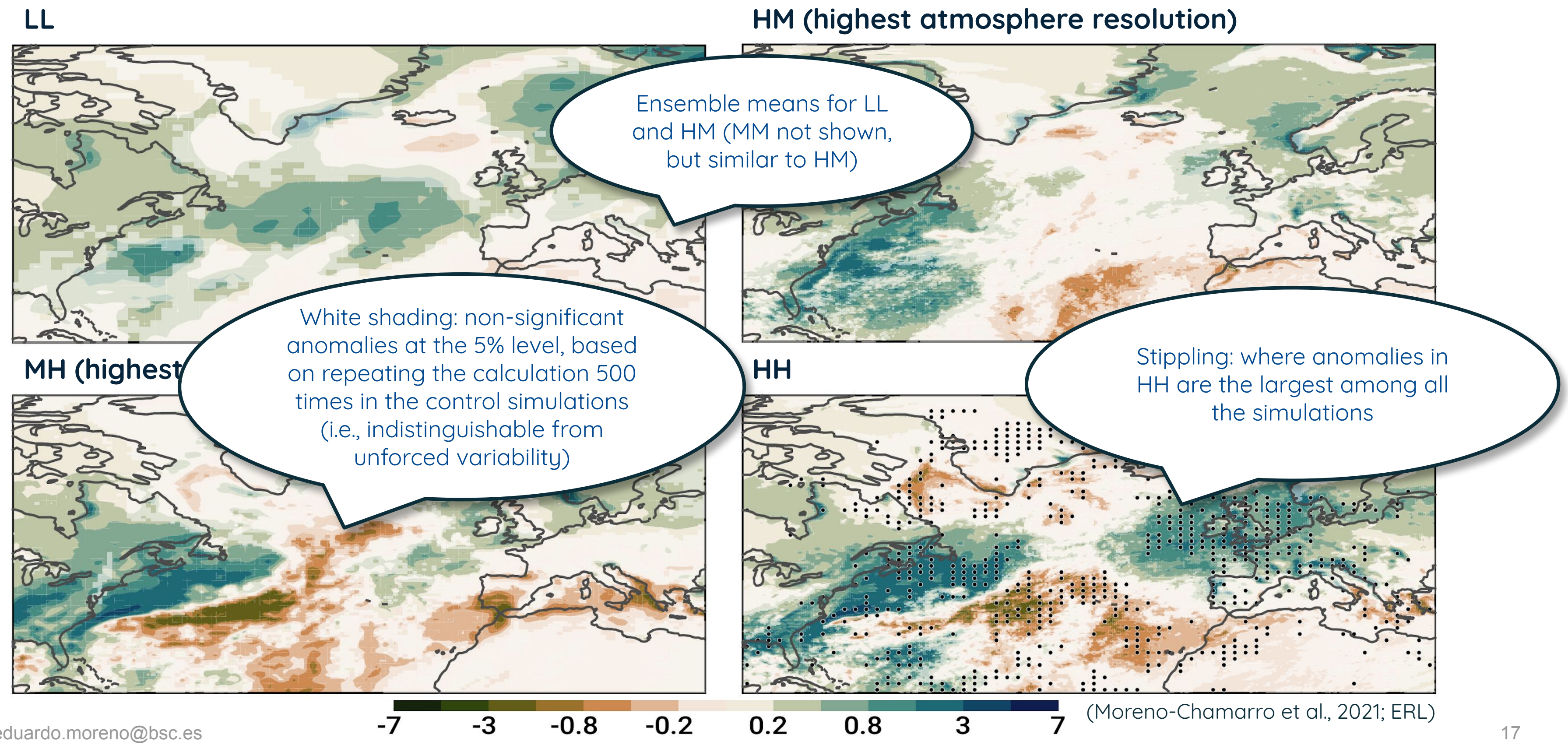


(Moreno-Chamarro et al., 2021; ERL)

eduardo.moreno@bsc.es

Winter precipitation increases the most in HH

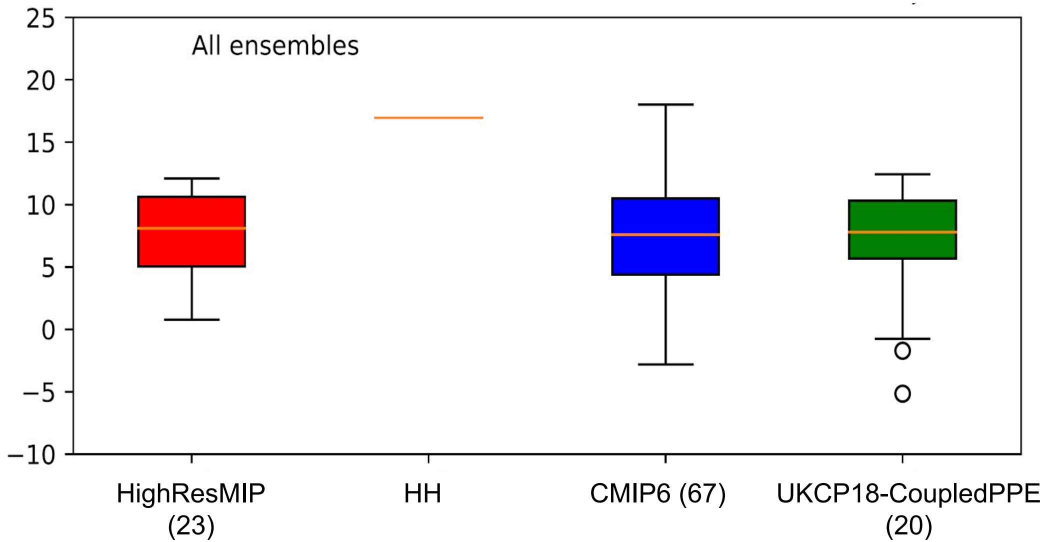
Anomalies in winter precip. (mm/day) between 2030–2050 and 1960–1980



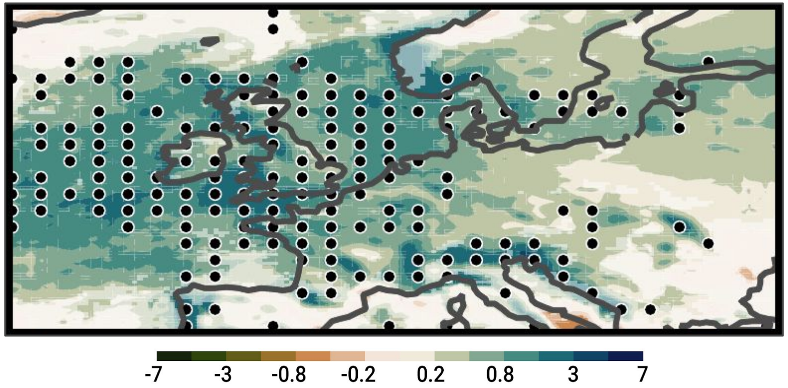
(Moreno-Chamarro et al., 2021; ERL)

Among all the ensembles, winter precipitation still increases the most in HH

Percentage of change (%) in winter precip between 2030–2050 and 1960–1980

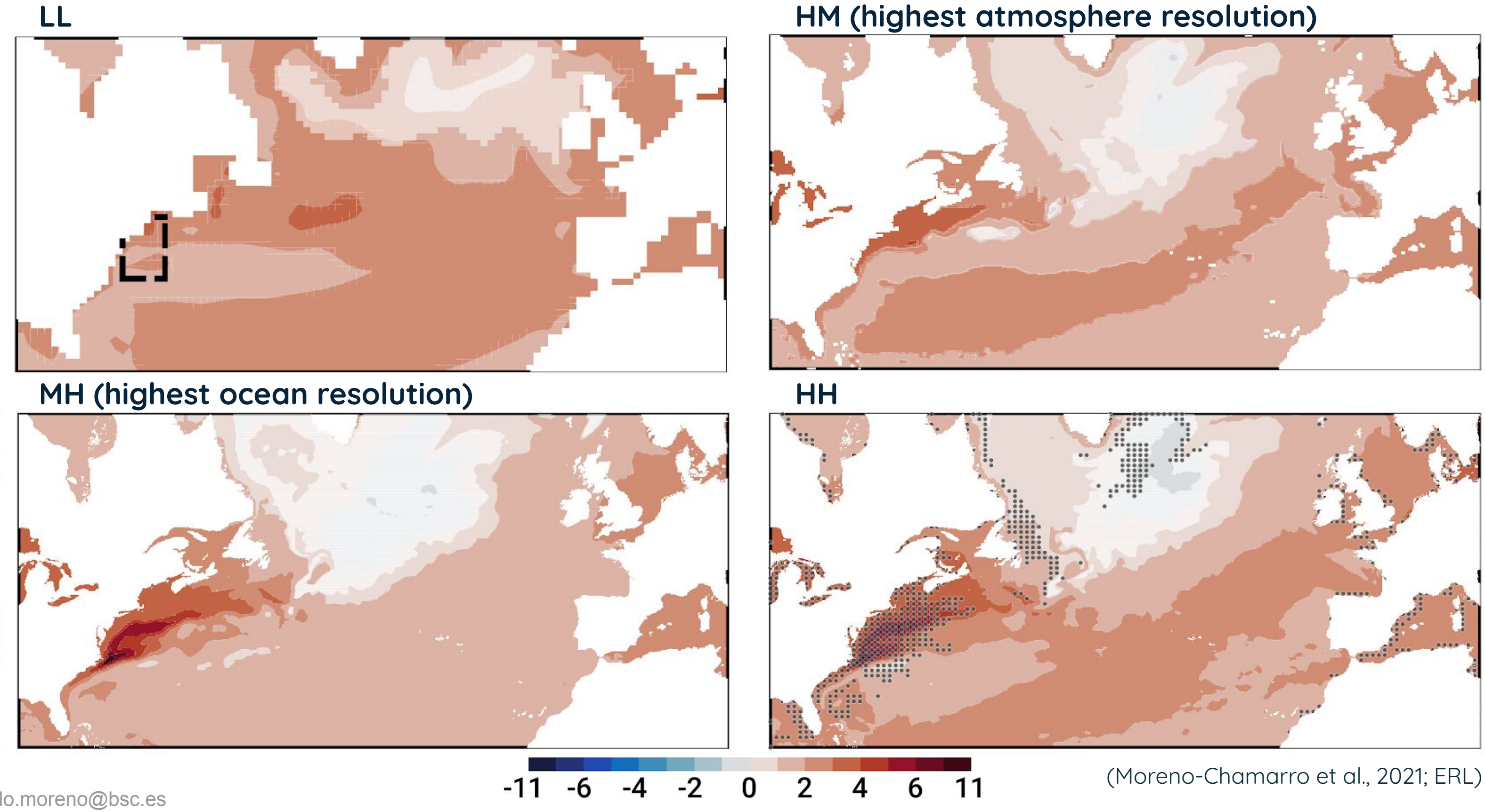


Change (mm/day) in winter precip between 2030–2050 and 1960–1980 in HH



Gulf Stream warming only at the eddy-rich ocean resolution

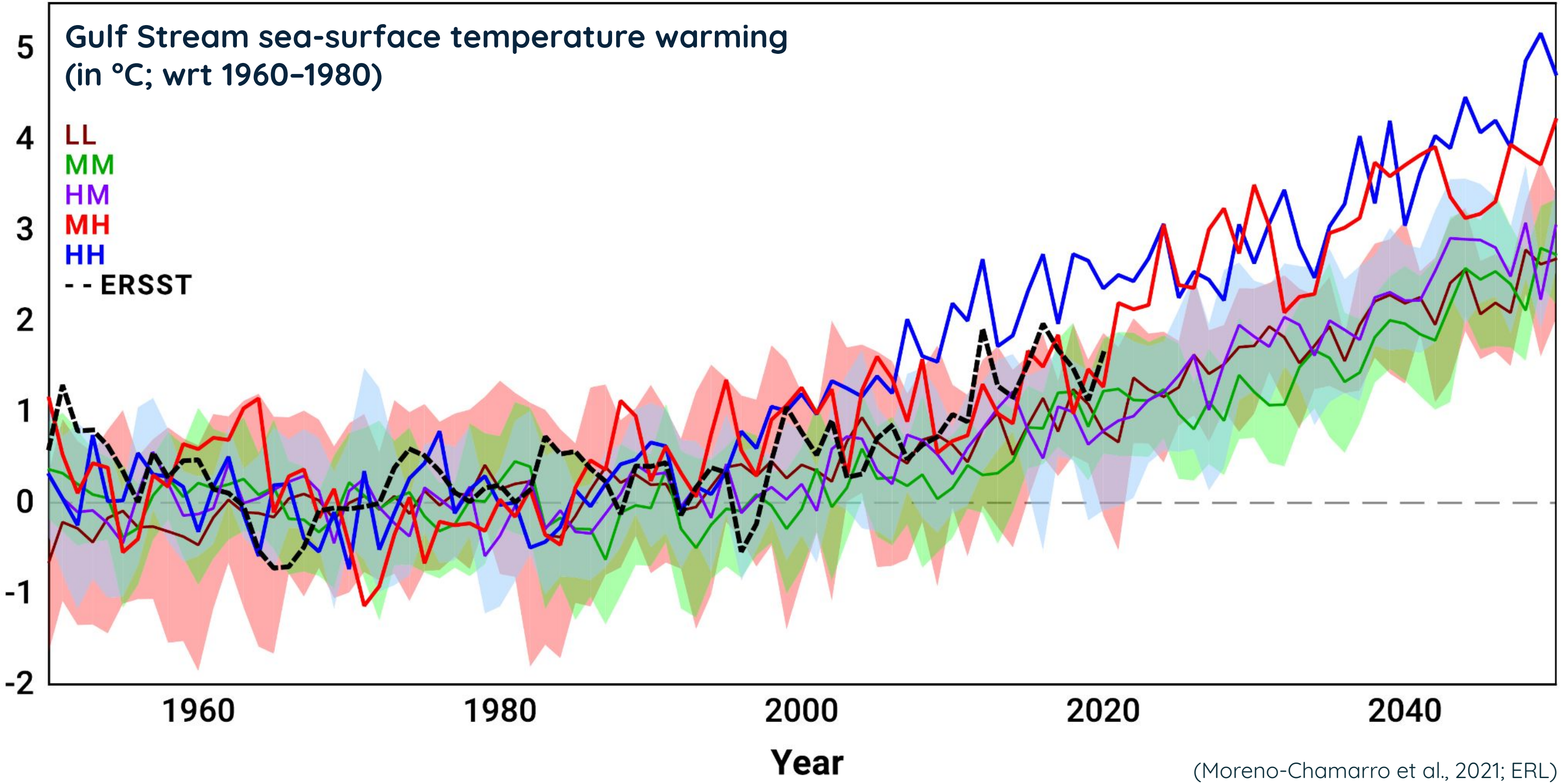
Anomalies in sea-surface temperature (°C) between 2030–2050 and 1960–1980



(Moreno-Chamarro et al., 2021; ERL)

eduardo.moreno@bsc.es

Gulf Stream warming only at the eddy-rich ocean resolution



(Moreno-Chamarro et al., 2021; ERL)

Unusual Gulf Stream warming getting detected in observations

Science | Current Issue | First release papers | Archive | About | More

HOME > SCIENCE > SLOW ADAPTATION IN THE FACE OF RAPID WARMING LEADS TO COLLAPSE OF THE GULF OF MAINE COD FISHERY

REPORT

Slow adaptation in the face of rapid warming leads to collapse of the Gulf of Maine cod fishery

ANDREW J. PERSHING, MICHAEL A. ALEXANDER, [...] ANDREW C. THOMAS +10 authors Authors Info & Affiliations

Article | Published: 23 September 2021

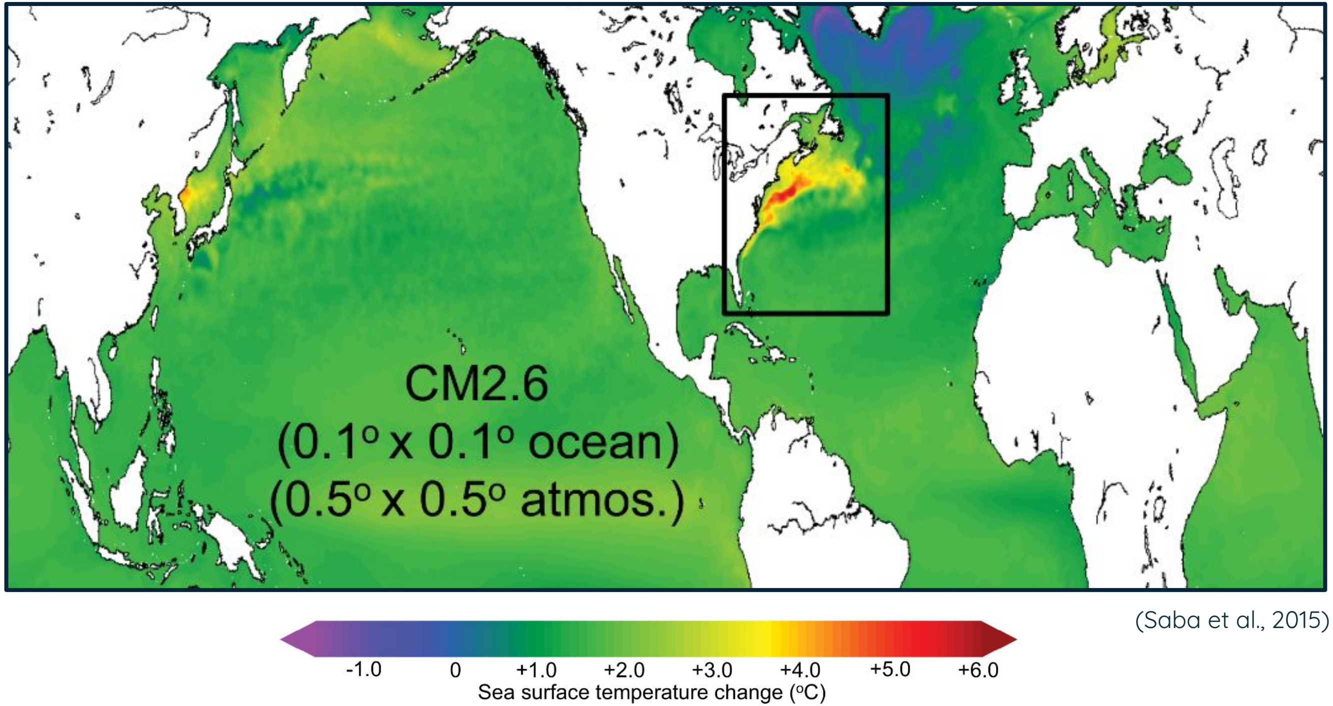
Drivers of exceptional coastal warming in the northeastern United States

Ambarish V. Karmalkar & Radley M. Horton

Nature Climate Change **11**, 854–860 (2021) | Cite this article

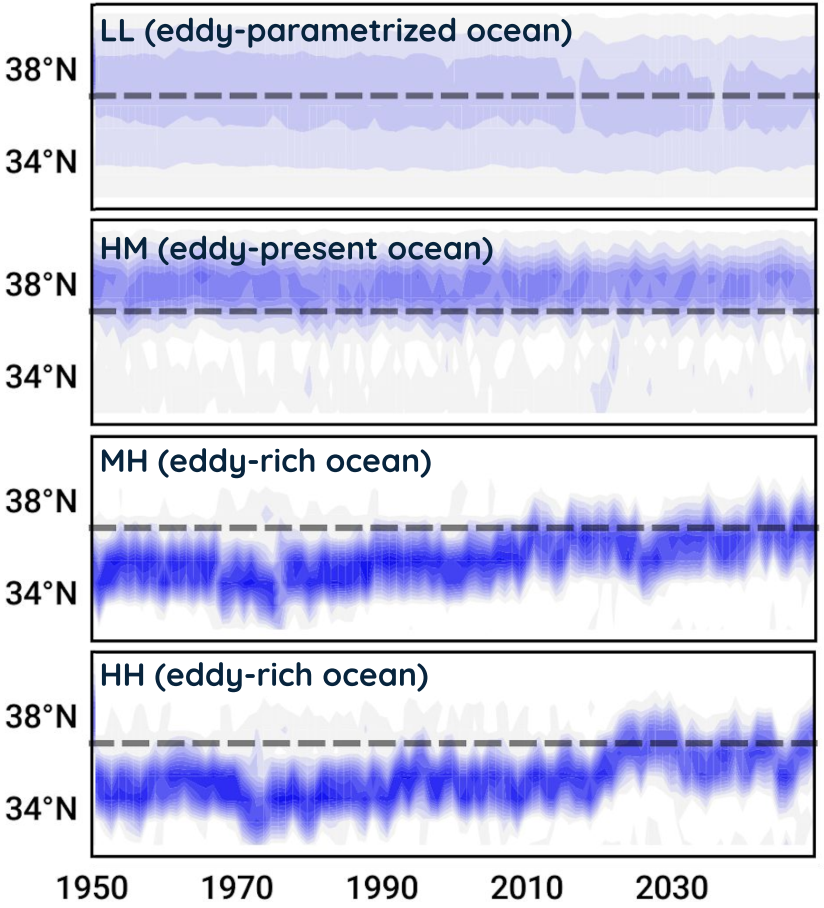
1203 Accesses | **201** Altmetric | Metrics

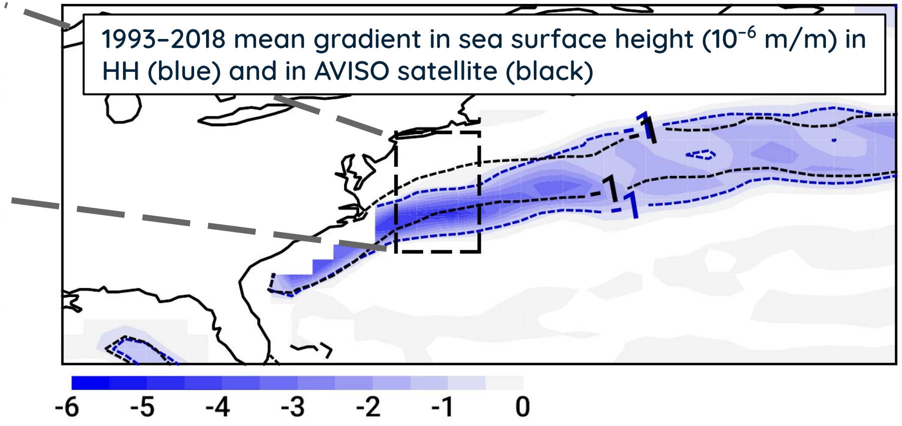
Unusual Gulf Stream warming also projected by an eddy-rich GFDL model version for a 4×CO_2 increase



(Saba et al., 2015)

Northward Gulf Stream shift drives surface warming





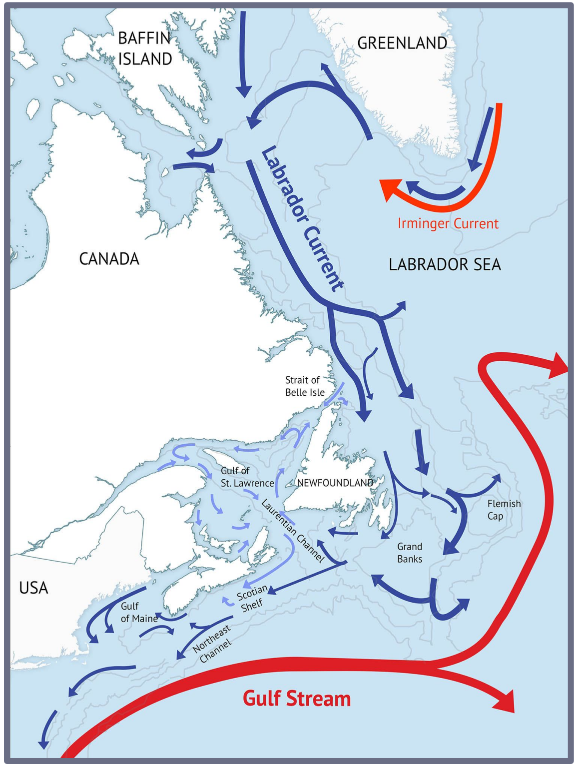
Shading: change in meridional gradient in sea-surface height (10^{-6} m/m)

Dashed line: 1993–2018 AVISO satellite climatology

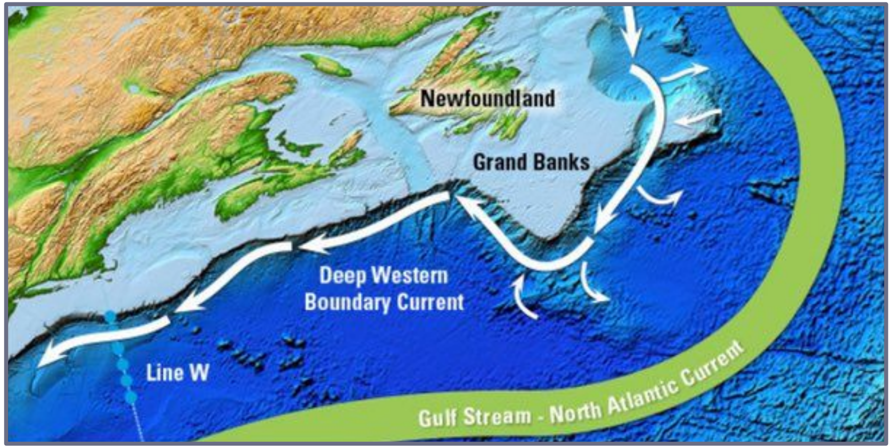
(Moreno-Chamarro et al., 2021; ERL)

Northward Gulf Stream shift linked to AMOC/Deep Western Boundary Current

Surface currents

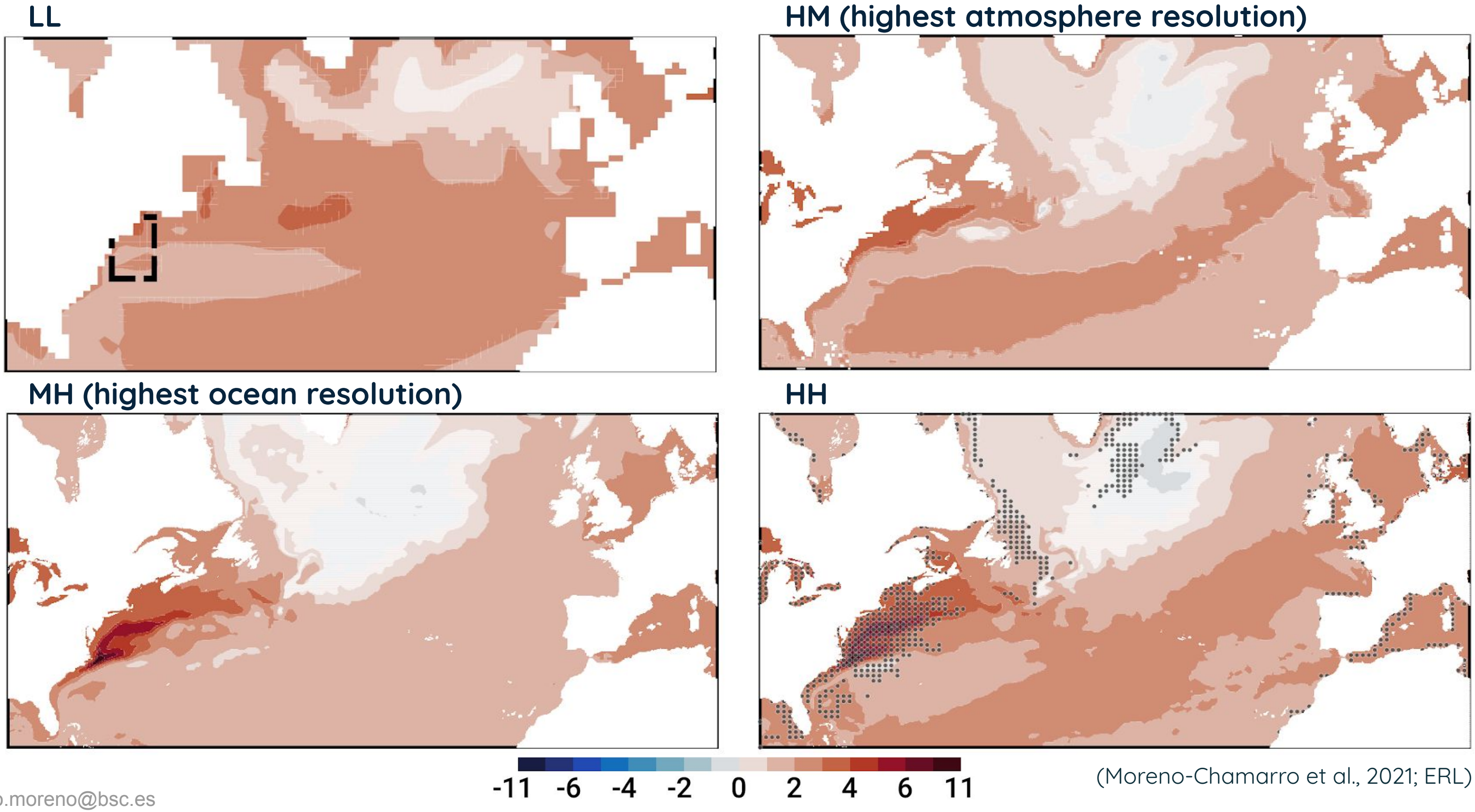


Deep Western Boundary Current



Gulf Stream warming only at the eddy-rich ocean resolution

Anomalies in sea-surface temperature (°C) between 2030–2050 and 1960–1980

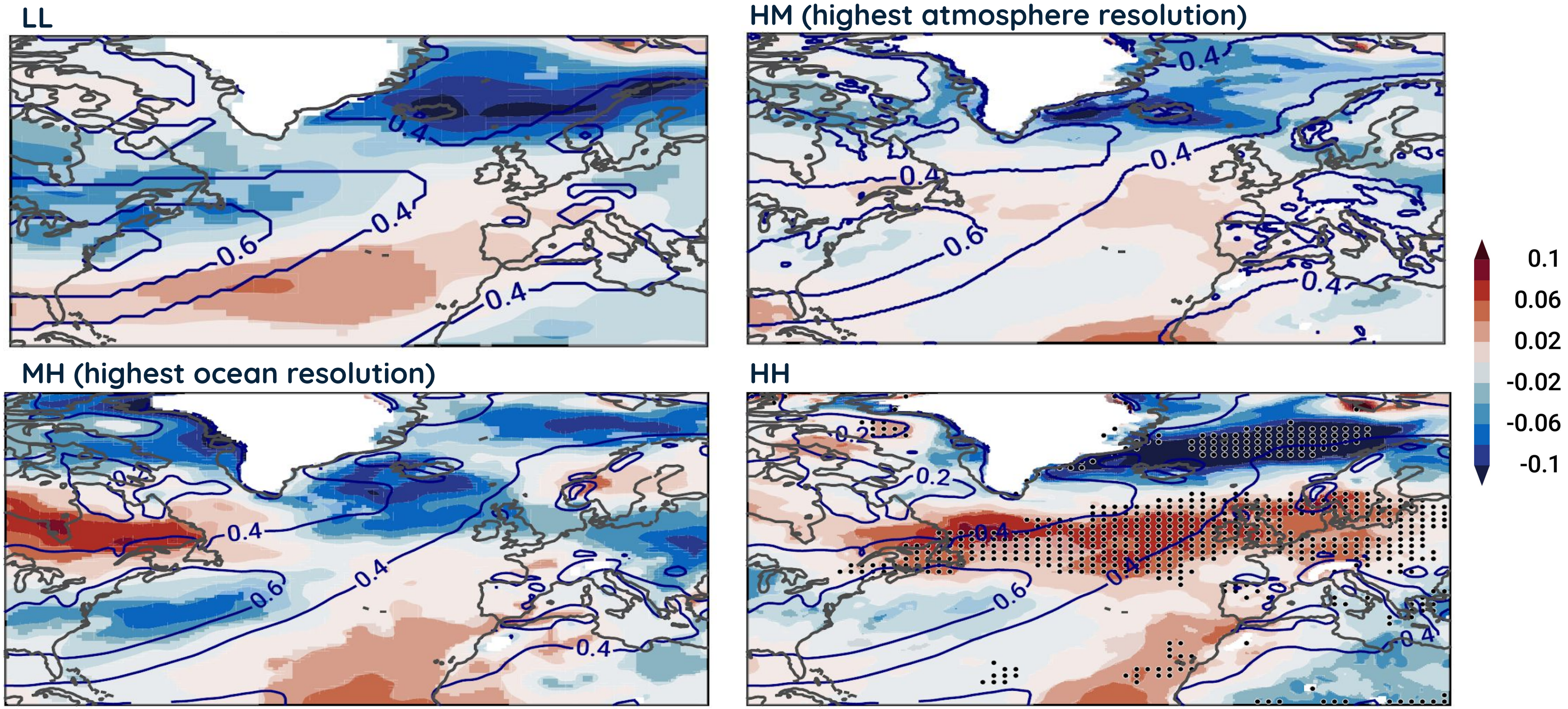


(Moreno-Chamarro et al., 2021; ERL)

eduardo.moreno@bsc.es

Strongest increase in mid-latitude cyclone activity in HH

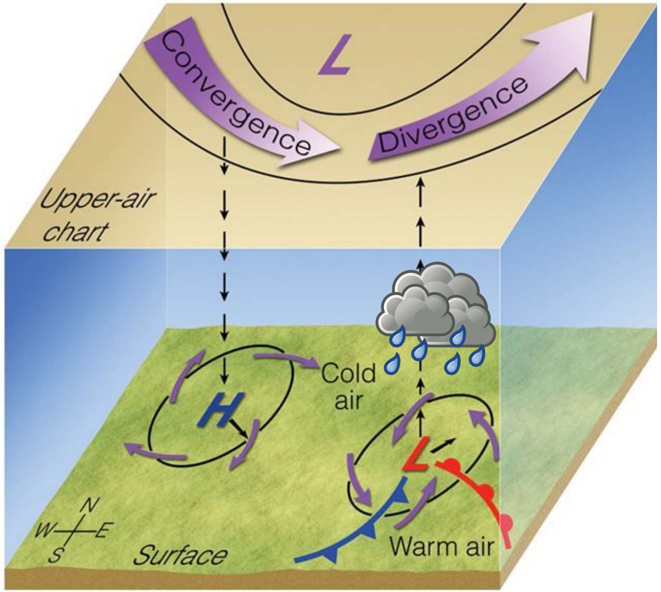
Anomalies in winter max. Eady growth rate (d^{-1}) at 700 hPa between 2030–2050 and 1960–1980



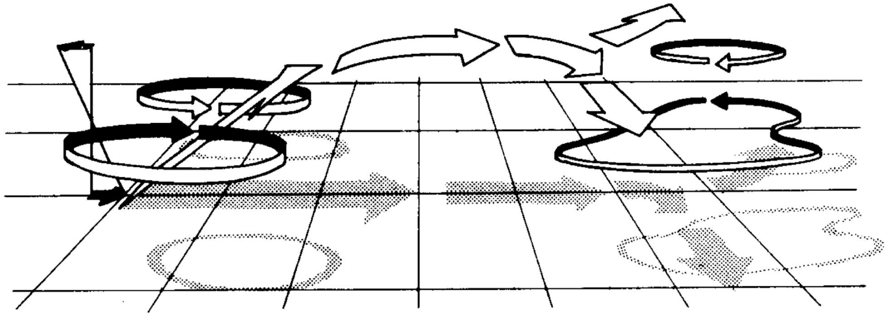
(Moreno-Chamarro et al., 2021; ERL)

Two mechanisms sustaining the increase in storm growth

Increased diabatic heating

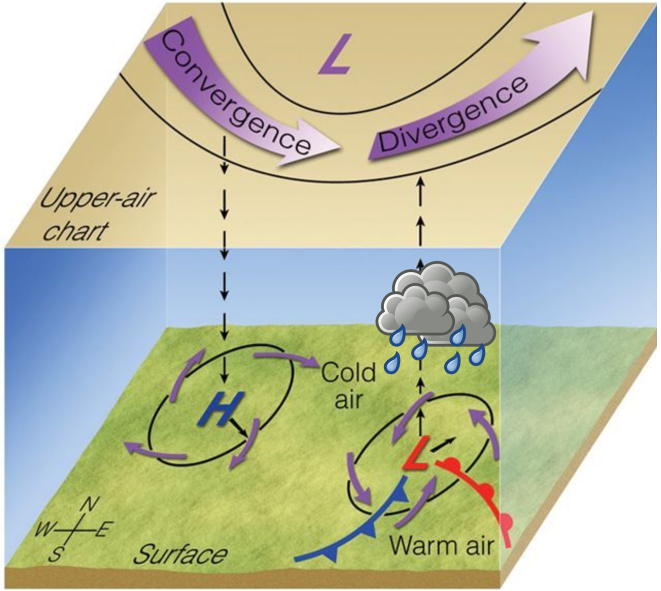


Accelerated upper-troposphere jet



(Hoskins et al., 1983)

Increased diabatic heating



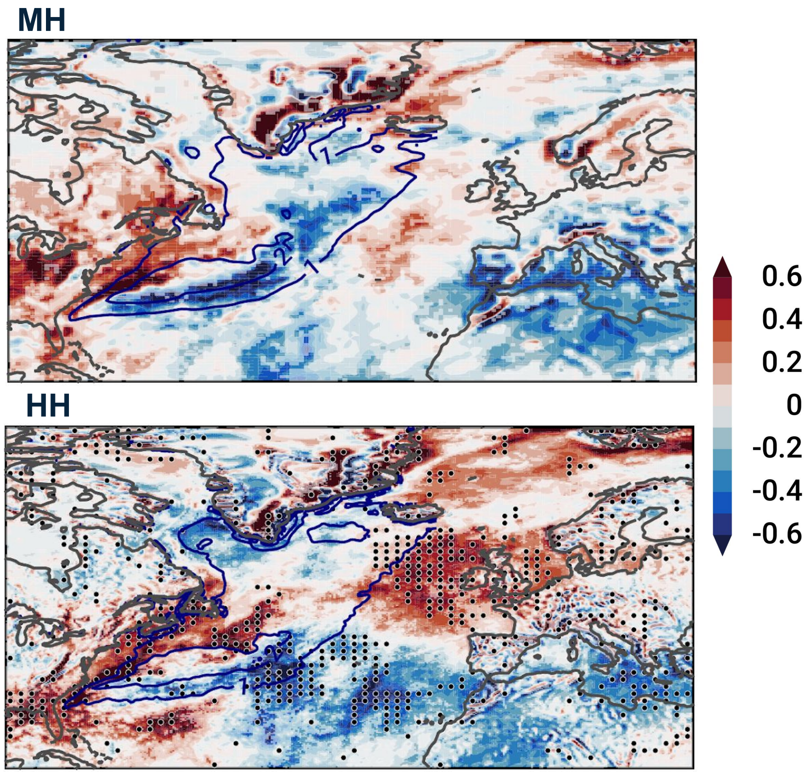
In better resolved **storm fronts**

Reinforcing the low-level cyclonic circulation, **L**, and the upper-level through, **L**, and so leading to further cyclone development

Fueled by additional **heating** due to Gulf Stream warming

Increased diabatic heating at the highest atmosphere resolution

Anomalies in 850–250 hPa diabatic heating (K/day)
between 2030–2050 and 1960–1980



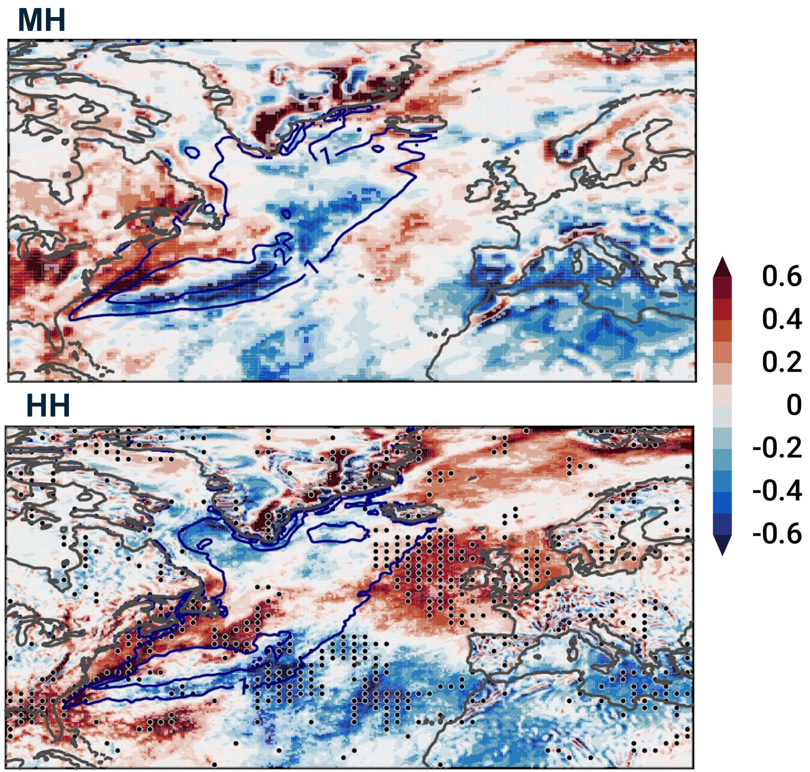
In better resolved **storm fronts**

Reinforcing the low-level cyclonic circulation, L, and the upper-level through, L, and so leading to further cyclone development

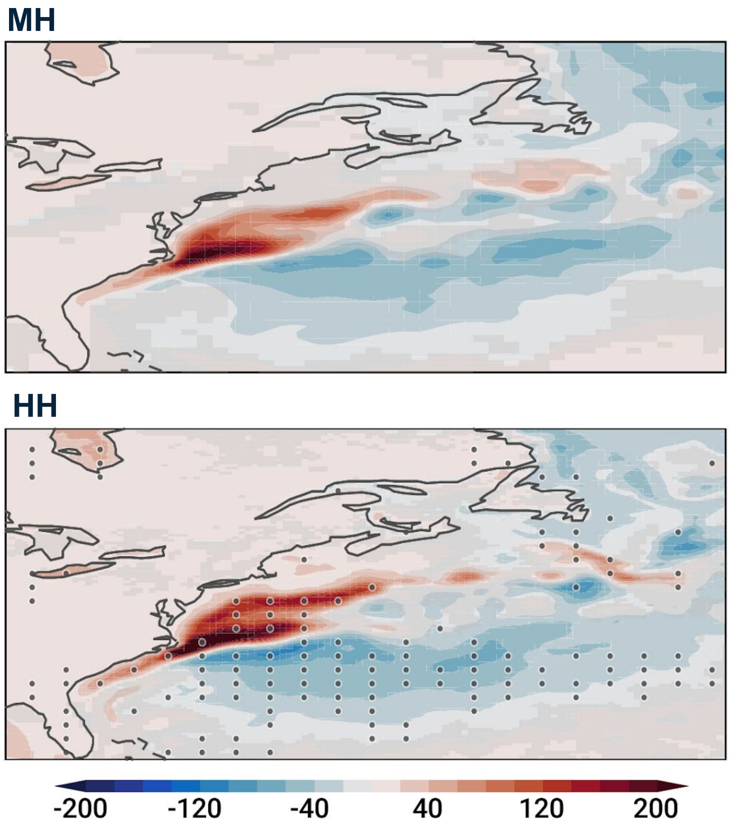
Fueled by additional **heating** due to Gulf Stream warming

Increased diabatic heating at the highest atmosphere resolution

Anomalies in 850–250 hPa diabatic heating (K/day) between 2030–2050 and 1960–1980

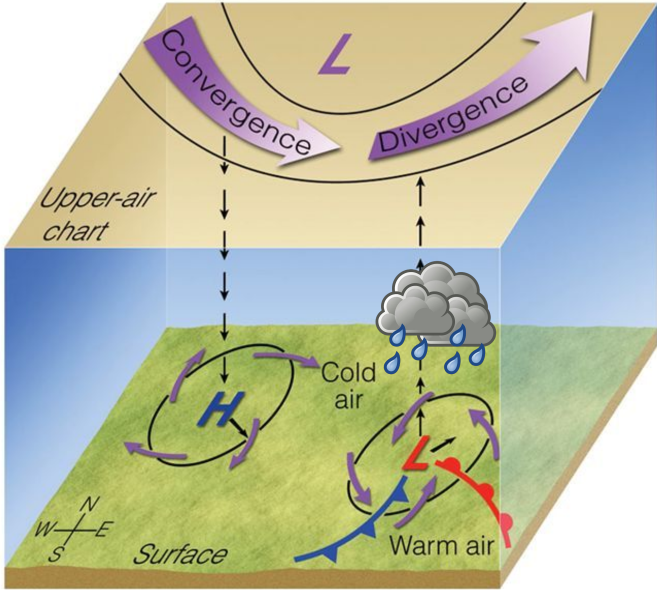


Anomalies in turbulent heat flux (W/m^2) between 2030–2050 and 1960–1980

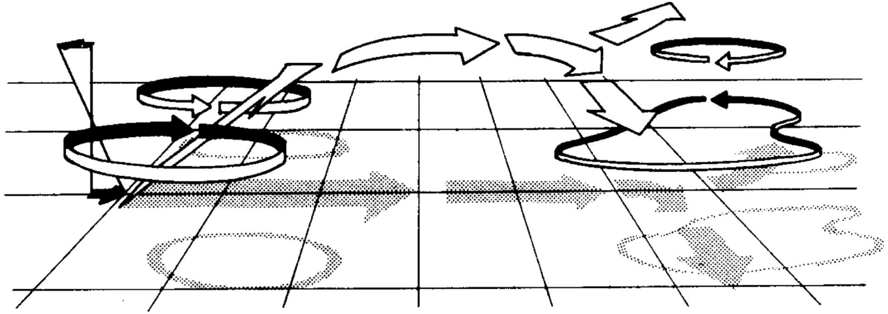


Two mechanisms sustaining the increase in storm growth

Increased diabatic heating



Accelerated upper-troposphere jet

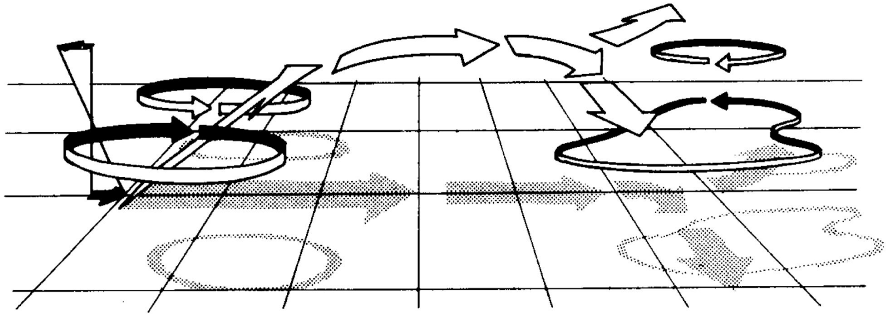


(Hoskins et al., 1983)

Accelerated upper-troposphere jet

Weakening atmosphere vertical stability (increasing vertical shear)

Enhanced eddy-mean flow **momentum** transfer



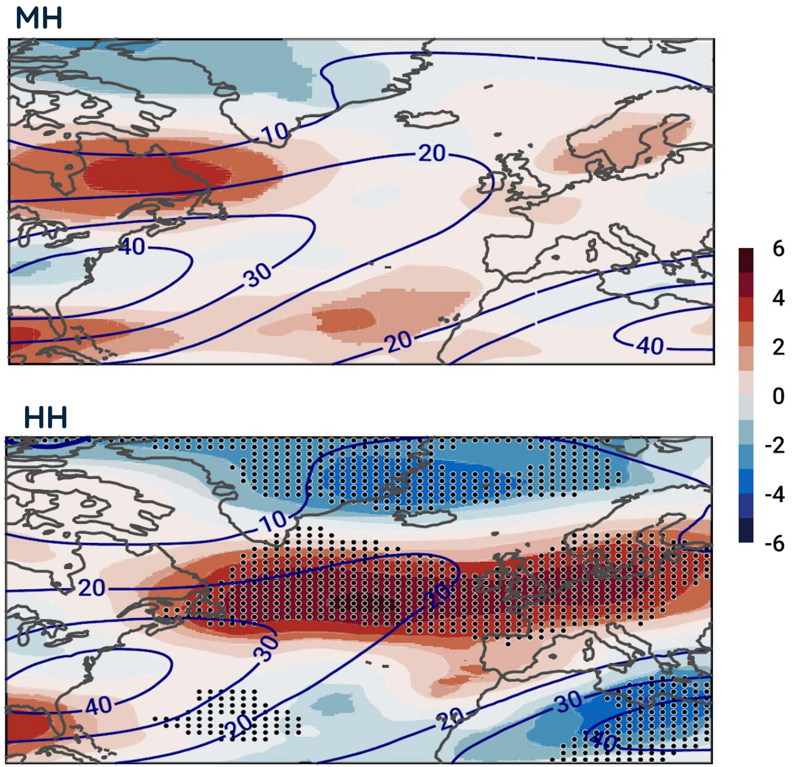
(Hoskins et al., 1983)

Accelerated upper-troposphere jet at the highest atmosphere resolution

Weakening atmosphere vertical stability (increasing vertical shear)

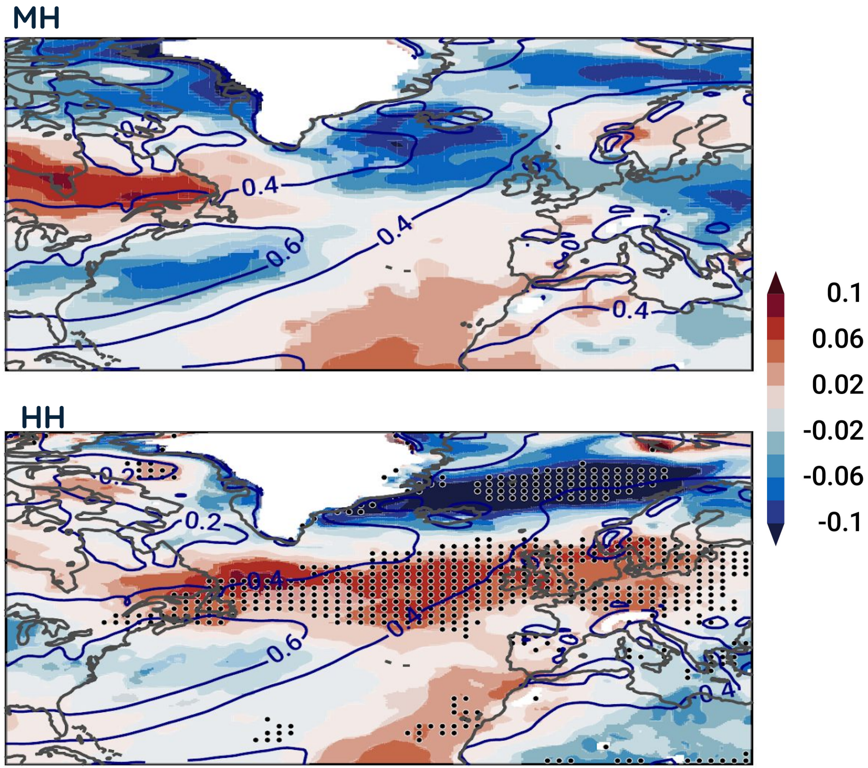
Enhanced eddy-mean flow **momentum** transfer

Anomalies in winter 250 hPa zonal wind (m/s) between 2030–2050 and 1960–1980

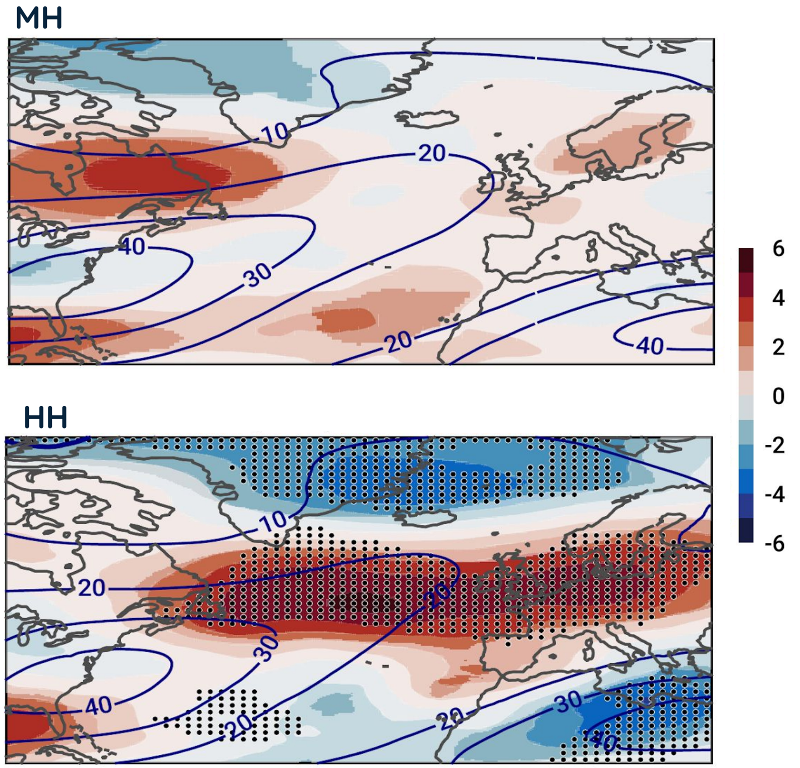


Accelerated upper-troposphere jet at the highest atmosphere resolution

Anomalies in winter 700 hPa max. Eady growth rate (d^{-1}) between 2030–2050 and 1960–1980

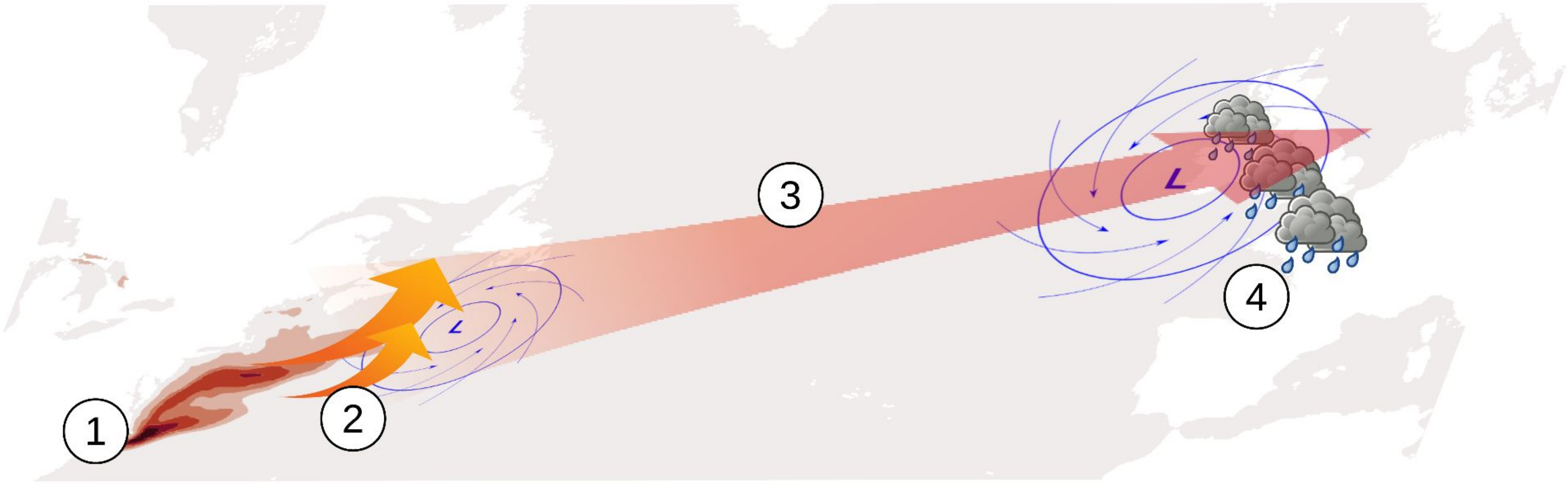


Anomalies in winter 250 hPa zonal wind (m/s) between 2030–2050 and 1960–1980

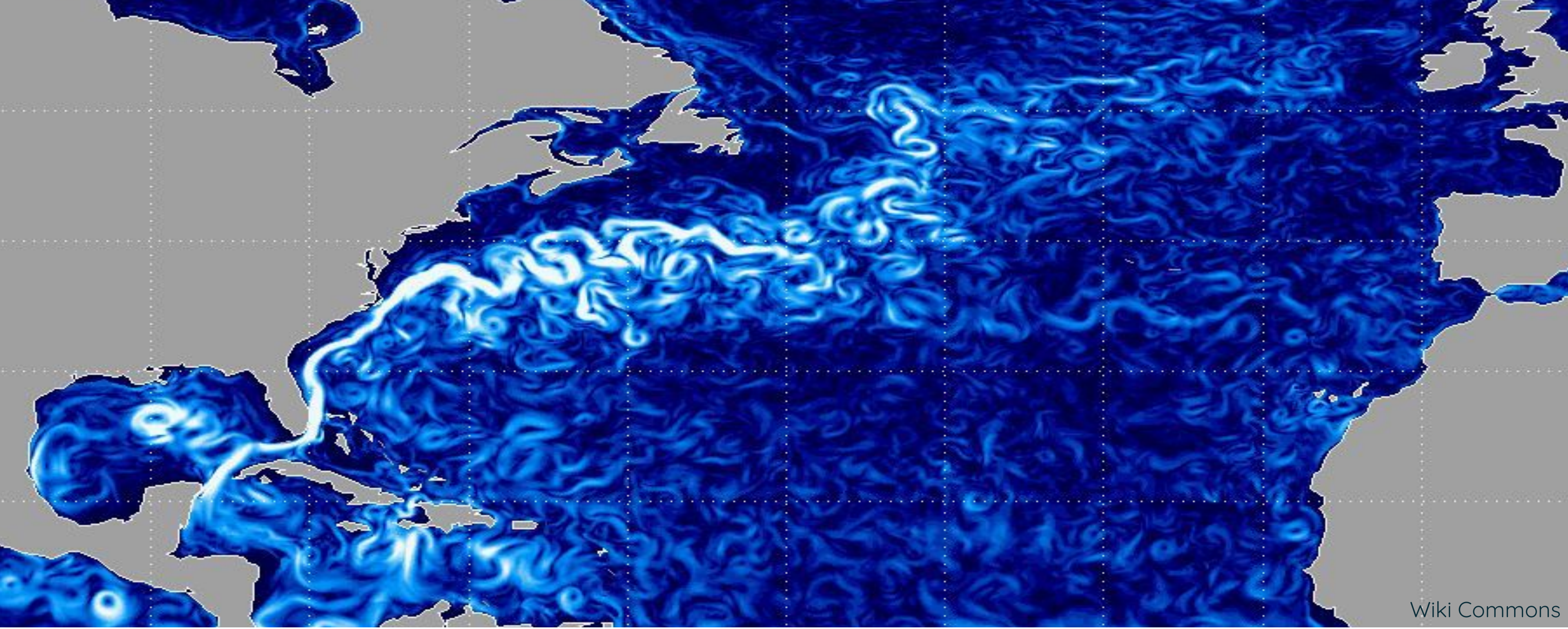


eduardo.moreno@bsc.es

Linking the Gulf Stream warming, strengthened extratropical cyclones, and increased precipitation in winter NW Europe



(Moreno-Chamarro et al., 2021; ERL)



STREAM: STirring the ocean: the Role of ocean Eddies in the north Atlantic circulation, Mid-latitude climate prediction, and impacts

eduardo.moreno@bsc.es

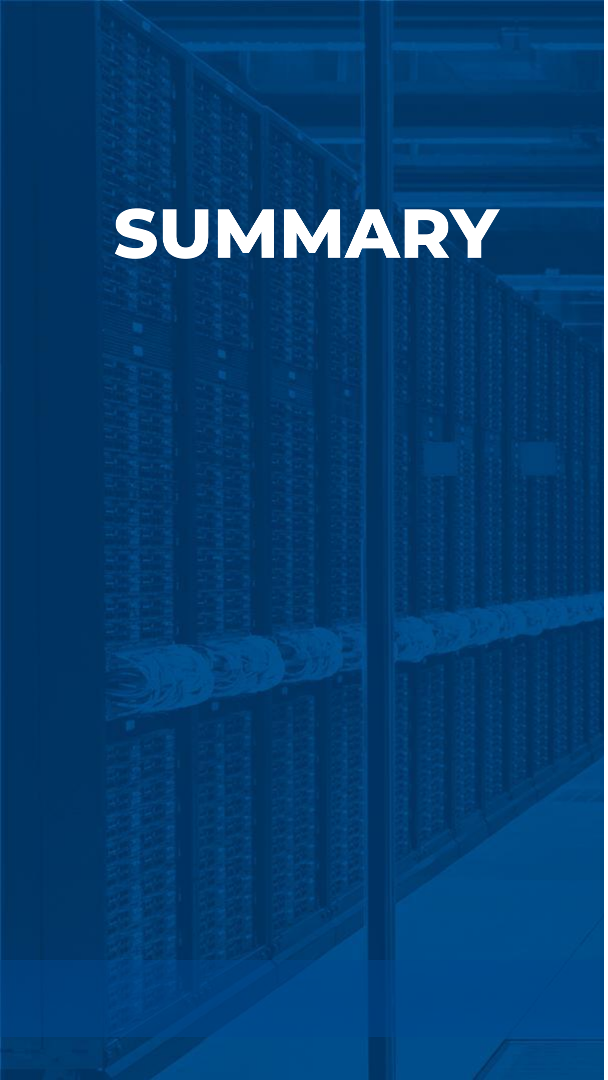
STREAM project: objectives and models

Quantify the impact of ocean mesoscale eddies on both present-day and future **North Atlantic ocean circulation**

Constrain how eddies shape the influence of the North Atlantic on the **European climate and future evolution**

Evaluate the impact of ocean eddies on the **near-term predictive skill** over Europe, with a main focus on surface air temperature and precipitation

EC-Earth-VHR (15-km atmosphere and ocean)
EC-Earth-HR (40-km atmosphere, and 25-km ocean)
In collaboration with Met Office, Max Planck Institute for Meteorology, and Texas A&M University/International Laboratory for High-Resolution Earth System Prediction



SUMMARY

1. **Alone, increased resolution from ~100 km to 25–50 km does not contribute to reducing biases substantially**
    - It depends on the model/resolution
    - Further model development, tuning, or even finer resolutions might be needed

2. **Differences in the Gulf Stream position, strength, and future change between non-eddy and eddy-rich models**
    - It can lead to a different future response to GHG increase

3. **New project, STREAM, to explore ocean mesoscale in the North Atlantic and impacts on climate and predictability**